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WL-TR-97-4041

PROCEEDINGS OF THE ANNUAL MECHANICS OF COMPOSITES REVIEW (4TH)

Sponsored by:

Air Force Materials Laboratory
Nonmetallic Materials Division of the

and

DOD/NASA Composites Interdependency Panel
on Tolerance and Durability

APRIL 1997

FINAL REPORT FOR PERIOD 31 OCTOBER 1978 - 2 NOVEMBER 1978

Approved for public release; distribution unlimited

MATERIALS DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AFB OH 45433-7734

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Materials Directorate Wright Laboratory Air Force Materiel Command Wright-Patterson AFB Ohio 45433-7734 POC:Tammy Oaks, WL/MLBM, 937-255-3068	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER** WL-TR-97-4041

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13. ABSTRACT *(Maximum 200 words)*

This report contains the basic unedited vu-graphs of the presentations at the "Mechanics" of Composites Review" sponsored jointly by the Non-metallic Materials Division of the Air Force Materials Laboratory, the Structures Division of the Air Force Flight Dynamics Laboratory and the Directorate of Aerospace Sciences of the Air Force Office of Scientific Research. The presentations cover current in-house and contract programs under the sponsorship of these three organizations.

14. SUBJECT TERMS	15. NUMBER OF PAGES
epoxy-matrix composites; composite materials; resin matrix composites; composite bonded joints; fatigue of graphite/epoxy composites; fracture and fatigue of bi-materials	215
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

FOREWORD

This report contains the basic unedited Vu-graphs of the presentations at the Fourth Mechanics of Composites Review sponsored jointly by the Nonmetallic Materials Division of the Air Force Materials Laboratory and the DOD/NASA Composites Interdependency Panel on Damage Tolerance and Durability. The presentations include an overview of each participating organizations program in mechanics of composite materials, followed by detailed presentations on specific programs. This is the first attempt to put together a detailed program covering activities throughout DOD and NASA. Programs not covered in detail in the present review are candidates for presentation at future mechanics of composites review. The presentations cover both in-house and contract programs under the sponsorship of the participating organizations.

Since this is a review of on-going programs, much of the information in this report has not been published as yet and is subject to changes, but timely dissemination of the rapidly expanding technology of advanced composites is deemed highly desirable. Works in the area of mechanics of composites have long been typified by disciplined approaches. It is hoped that such a high standard of rigor is reflected in the majority, if not all, of the presentations in this report.

Feedback and open critique of the presentations are welcome. Comments concerning the desirability of continuing the mechanics of composites review in conjunction with DOD/NASA Composites Interdependence Program are especially welcome. Special thanks are due to James M. Whitney of the Nonmetallic Materials Division for his effort in organizing this review. Again, suggestions and recommendations from all participants will be most important in the planning of future reviews.

J. M. KELBLE, Chief
Nonmetallic Materials Division
Air Force Materials Laboratory

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DOD/NASA COMPOSITES INTERDEPENDENCE PROGRAM

DAMAGE TOLERANCE AND DURABILITY PANEL

Robert M. Bader
Air Force Flight Dynamics Laboratory
Wright-Patterson AFB, OH

John R. Davidson
NASA Langley Research Center
Hampton, VA

Lee W. Gause
Naval Air Development Center
Warminster, PA

Arthur J. Gustafson
Army Applied Technology Laboratory
Ft. Eustis, VA

Gary R. Halford
NASA Lewis Research Center
Cleveland, OH

H. F. Hardrath
NASA Langley Research Center
Hampton, VA

T. E. Hess
Naval Air Development Center
Warminster, PA

Shih L. Huang
Naval Air Development Center
Warminster, PA

Edward F. Kautz
Naval Air Development Center
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Air Force Office of Scientific Research
Bolling AFB, DC

Edward W. Ogska
Naval Air Development Center
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Warminster, PA

James H. Starnes, Jr.
NASA Langley Research Center
Hampton, VA

J. M. Whitney
Air Force Materials Laboratory
Wright-Patterson AFB, OH

AGENDA

MECHANICS OF COMPOSITES REVIEW

OCTOBER 31, NOVEMBER 1-2, 1978

TUESDAY, OCTOBER 31

7:45 AM	REGISTRATION
8:30	OPENING REMARKS: Dr. N. M. Tallan, Chief Scientist, Air Force Materials Laboratory
8:40	PURPOSE OF MEETING: R. M. Bader, Air Force Flight Dynamics Laboratory, Chairman, DOD/NASA Composites Interdependence Panel on Damage Tolerance and Durability
8:45	OVERVIEW - NASA PROGRAM: H. F. Hardrath, NASA Langley Research Center
9:00	COMPOSITES FOR ENGINE APPLICATION: C. C. Chamis, NASA Lewis Research Center
9:30	ENVIRONMENTAL EFFECTS ON COMPOSITES: B. Stein, NASA Langley Research Center
10:00	COFFEE BREAK
10:30	FATIGUE OF COMPOSITES: L. G. Roderick, NASA Langley Research Center
11:00	FATIGUE OF JOINTS AND DAMAGE TOLERANCE IN COMPOSITES: John R. Davidson, NASA Langley Research Center
11:30	ADVANCED COMPOSITE COMPRESSION STRUCTURES: J. H. Starnes, NASA Langley Research Center
12:00	LUNCH
1:00 PM	OVERVIEW - AIR FORCE OFFICE OF SCIENTIFIC RESEARCH PROGRAMS: Dr. Brian Quinn, Director of Aerospace Sciences, OSR
1:15	SPACE ENVIRONMENTAL EFFECTS ON ADVANCED COMPOSITES: R. C. Tenneyson, University of Toronto

1:55 PM COMPOSITES FOR STRUCTURAL DESIGN: R. Schapery and H. Cherry, Texas A&M

2:35 COFFEE BREAK

3:05 COUPLED DIFFUSION IN COMPOSITES: G. C. Sih, Lehigh University

3:45 FAILURE PROCESSES IN ADVANCED COMPOSITE STRUCTURES: L. W. Rehfield, Georgia Institute of Technology

4:25 FRACTURE OF ADHESIVE JOINTS AND ADVANCED COMPOSITES: W. G. Knauss, California Institute of Technology

5:15 COCKTAIL PARTY: Bergamo Center

WEDNESDAY, NOVEMBER 1

8:00 AM OVERVIEW - AIR FORCE MATERIALS LABORATORY PROGRAM: J. M. Whitney, Nonmetallic Materials Division, AFML

8:15 DEFECT/PROPERTY RELATIONSHIPS IN COMPOSITE LAMINATES: K. L. Reifsnider, Virginia Polytechnic Institute and State University

9:00 CHARACTERIZATION OF FATIGUE DAMAGE CRACKS IN COMPOSITE LAMINATES: R. Y. Kim, University of Dayton Research Institute

9:30 TORSION TEST TO DETERMINE TRANSVERSE SHEAR MODULUS: N. J. Pagano and F. K. Huber, Air Force Materials Laboratory

10:00 COFFEE BREAK

10:30 EFFECT OF MOISTURE ON THE COMPRESSION STRENGTH OF LAMINATED EPOXY MATRIX COMPOSITES: K. N. Lauraitis, Lockheed California Company, Rye Canyon Research Laboratory

11:15 STATISTICAL FAILURE ANALYSIS OF COMPOSITES: P. C. Chou, Drexel University

12:00 LUNCH

1:00 PM	OVERVIEW - AIR FORCE FLIGHT DYNAMICS LABORATORY PROGRAM: G. Sendeckyj, Structures Division, AFFDL
1:15	AFFDL RESEARCH ACTIVITIES: G. Sendeckyj, Air Force Flight Dynamics Laboratory
1:45	DETERMINATION OF MOISTURE CONTENT IN COMPOSITES BY DIELECTRIC MEASUREMENTS: Ancil Kays, Lockheed-Georgia Company
2:15	FATIGUE SPECTRUM SENSITIVITY STUDY FOR ADVANCED COMPOSITE MATERIALS: L. L. Jeans, Northrop Corporation
2:50	COFFEE BREAK
3:20	ENVIRONMENTAL SENSITIVITY OF ADVANCED COMPOSITES: J. B. Whiteside, Grumman Aerospace Corp.
3:55	ADVANCED COMPOSITE SERVICEABILITY PROGRAM: Donald Konishi, Rockwell International Company
4:30	EFFECT OF SERVICE ENVIRONMENT ON THE F-15 BORON-EPOXY STABILATOR: Thomas V. Hinkle, McDonnell Aircraft Company
5:00	ADJOURN

THURSDAY, NOVEMBER 2

8:00 AM	OVERVIEW - ARMY APPLIED TECHNOLOGY LABORATORY PROGRAM: A. J. Gustafson, Applied Technology Laboratory
8:15	INVESTIGATION OF ADVANCED CONCEPTS FOR COMPOSITE STRUCTURE JOINTS AND ATTACHMENT FITTINGS: W. F. Rahhal, Hughes Helicopter Corporation
9:00	INVESTIGATION OF THE IMPACT CHARACTERISTICS OF ADVANCED AIRFRAME STRUCTURES: J. Cronkhite, Bell Helicopter Company and R. Winter, Grumman Aerospace Corporation
9:45	COFFEE BREAK
10:15	OVERVIEW - NAVAL AIR DEVELOPMENT COMMAND PROGRAM: M. S. Rosenfeld, Naval Air Development Center

10:30 AM EFFECT OF ENVIRONMENT ON THE MECHANICAL BEHAVIOR OF AS 3501-6 GRAPHITE EPOXY MATERIALS: W. J. Renton and T. L. Ho, Vought Corporation

11:05 IMPROVED DAMAGE TOLERANCE OF THICK GRAPHITE EPOXY LAMINATES: N. M. Bhatia, Northrop Corporation

11:50 ENVIRONMENTAL DEGRADATION OF SANDWICH CONSTRUCTION: K. E. Hofer and G. Waring, IIT Research Institute

12:30 ADJOURN

NASA RESEARCH ON
MECHANICS OF COMPOSITES
AND RELATED SUBJECTS

Herbert F. Hardrath
Materials Division
Langley Research Center

OVERVIEW TOPICS

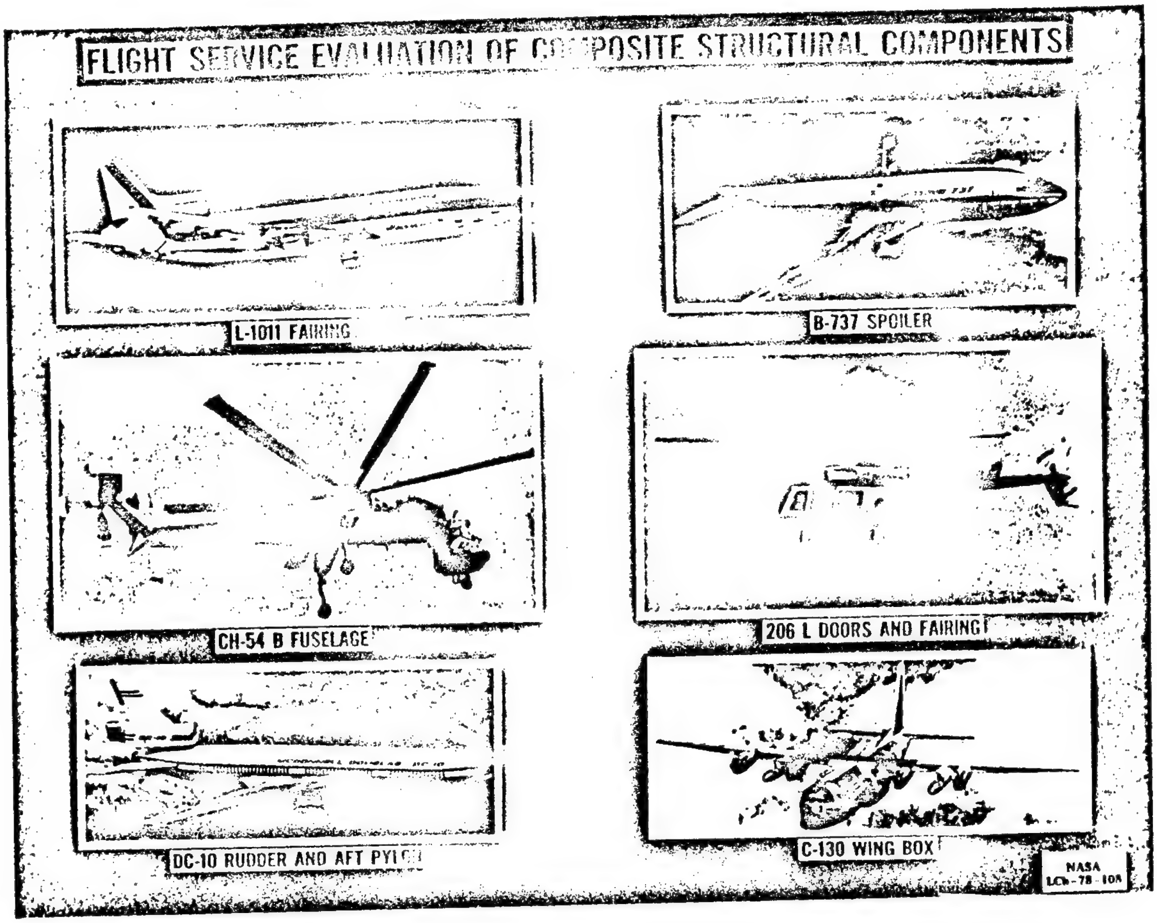
FLIGHT SERVICE

AIRCRAFT ENERGY EFFICIENCY (ACEE)

GRAPHITE FIBER ELECTRICAL HAZARD

ALTERNATE MATERIALS DEVELOPMENT

COMPOSITES FOR ADVANCED SPACE TRANSPORTATION SYSTEM (CASTS)

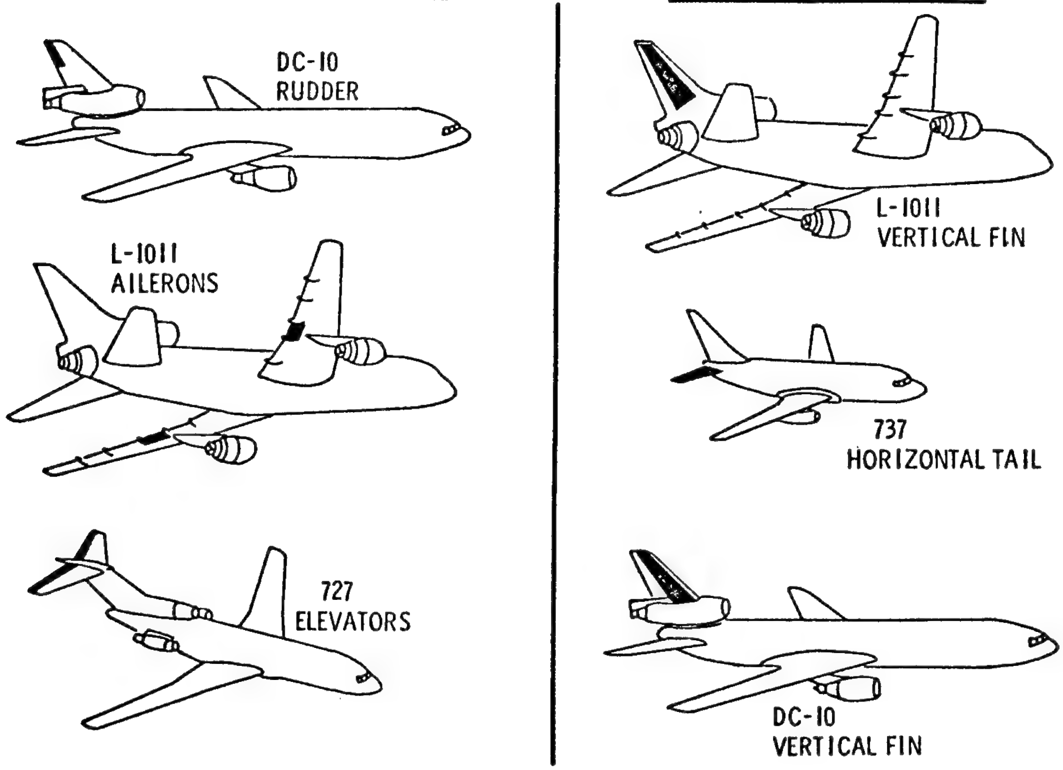


COMPOSITE STRUCTURES FLIGHT SERVICE PROGRAM
(SEPTEMBER 1, 1978)

AIRCRAFT, COMPONENT	TOTAL COMPONENTS	START OF FLIGHT SERVICE	CUMULATIVE FLIGHT HOURS	
			HIGH TIME AIRCRAFT	TOTAL COMPONENT
CH-54B TAIL CONE	1	MARCH 1972	1,130	1,130
L-1011 FAIRING PANELS	18	JANUARY 1973	14,951	221,130
737 SPOILER	108	JULY 1973	13,506	1,058,560
C-130 CENTER WING BOX	2	OCTOBER 1974	2,815	5,615
DC-10 AFT PYLON SKIN	3	AUGUST 1975	8,800	26,000
DC-10 UPPER AFT RUDDER	10	APRIL 1976	9,426	49,035
GRAND TOTAL	142			1,361,470

A C E E COMPOSITE COMPONENTS

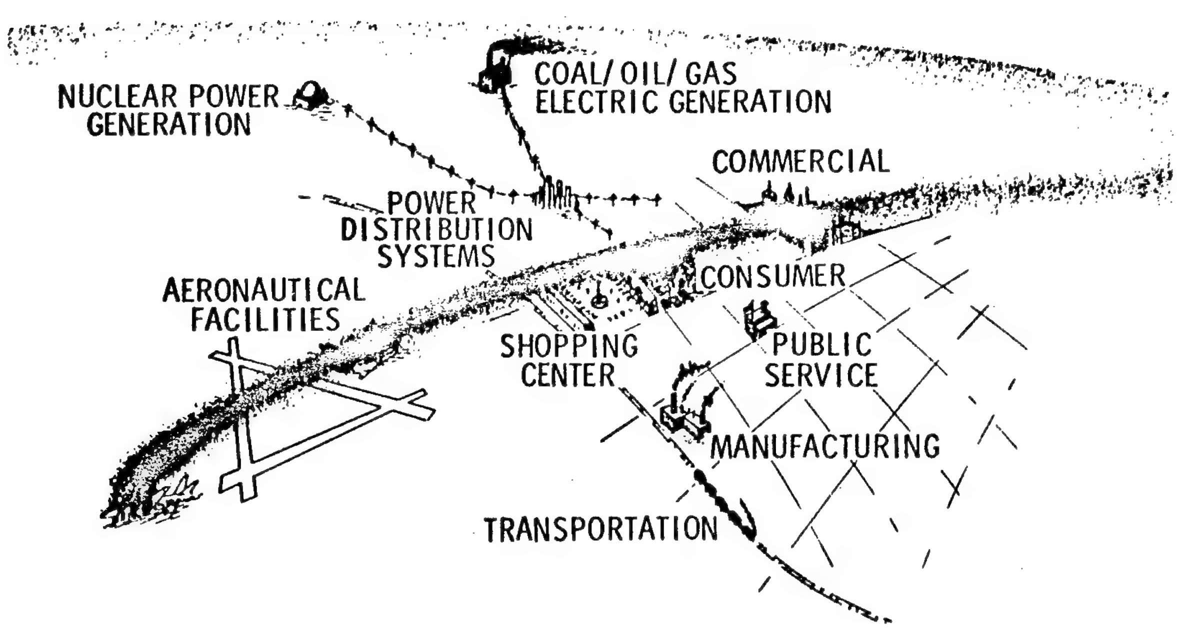
SECONDARY STRUCTURES | PRIMARY STRUCTURES



ACEE COMPOSITE COMPONENTS SUMMARY

COMPONENT	METAL DESIGN BASELINE WT. kg	COMPOSITE DESIGN ESTIMATED WT. kg	EXPECTED WT. SAVINGS %	NO. PER AIRCRAFT	QUANTITY TO BE BUILT
727 ELEVATOR	128.3	92.7	28	2	11 (1 G.T.)
DC-10 RUDDER	41.3	27.7	33	1	11 (1 G.T.)
L-1011 AILERON	63.5	47.5	25	2	22 (2 G.T.)
737 HOR. STAB.	118.2	86.2	27	2	11 (1 G.T.)
DC-10 VERT. TAIL	423.4	337.6	20	1	8 (2 G.T.)
L-1011 VERT. TAIL	389.0	292.8	25	1	3 (2 G.T.)

RISK ANALYSIS SCENARIOS



STATUS OF RISK ANALYSIS PROGRAM

Release of Fibers

- Dependent upon agitation of residue
- Less than 1-2% released as single fibers
- Most single fibers are very short (less than 3 mm)

Dissemination

- Footprints of fibers may be greater than first expected
- Higher plume heights give longer, broader footprints; but lower fiber concentrations

Vulnerability

- Greatest risk to low voltage (5-6 volts) electronics
- Many 110 volt motors and appliances are invulnerable
- High voltage (over 440 volts) effects not established

Protection

- Conformal coatings, filters offer some protection

ALTERNATE MATERIALS THAT PROVIDE LESS ELECTRICAL RISK

GOALS: 1. PROVIDE FIBERS HAVING HIGH RESISTIVITY
RETAIN OR IMPROVE STRENGTH

2. INHIBIT GRAPHITE RELEASE IN FIRES

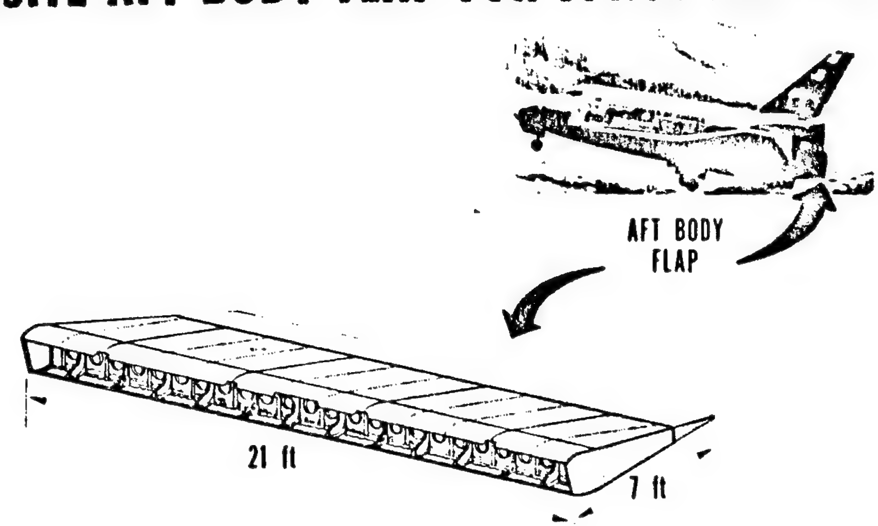
STATUS:

FIBER MODIFICATION	FIBER TYPE	R/R_0	EFFECT ON STRENGTH
INTERCOLATE GR WITH O_2	TYPE P FIBERS	10,000	NOT MEASURED
	GY-70	2,000	
	T300	100	
	HMS	10	
SPECIAL PROCESS TO ALTER GR STRUCTURE	PITCH GRADES	50,000	NONE
OXIDIZED SI C COATED FIBERS	HTS	1,000,000	NOT MEASURED

HYBRIDIZED COMPOSITES

GLASS OUTER LAYERS
BORON OUTER LAYERS } GREATLY REDUCE QUANTITY OF FIBER RELEASED
KEVLAR OUTER LAYERS — NO EFFECT, KEVLAR BURNS

COMPOSITE AFT BODY FLAP FOR SPACE SHUTTLE



MATERIAL	STRUCTURAL WEIGHT, lb	TPS WEIGHT, lb	TOTAL WEIGHT, lb
ALUMINUM	450	872	1322
Gr/Pi	356	615	971
Δ WEIGHT	94	257	351

MATERIALS EVALUATED FOR ELEVATED TEMPERATURE SERVICE

MATRIX

NR150B2	~~PMR-15-II~~	~~NR150A/B~~	~~PPQ~~
PMR-15	~~HR600~~	~~P13N~~	~~X5230~~
LARC-160	~~F178~~	~~S703~~	
THERMID 600	~~K601~~	~~S710~~	

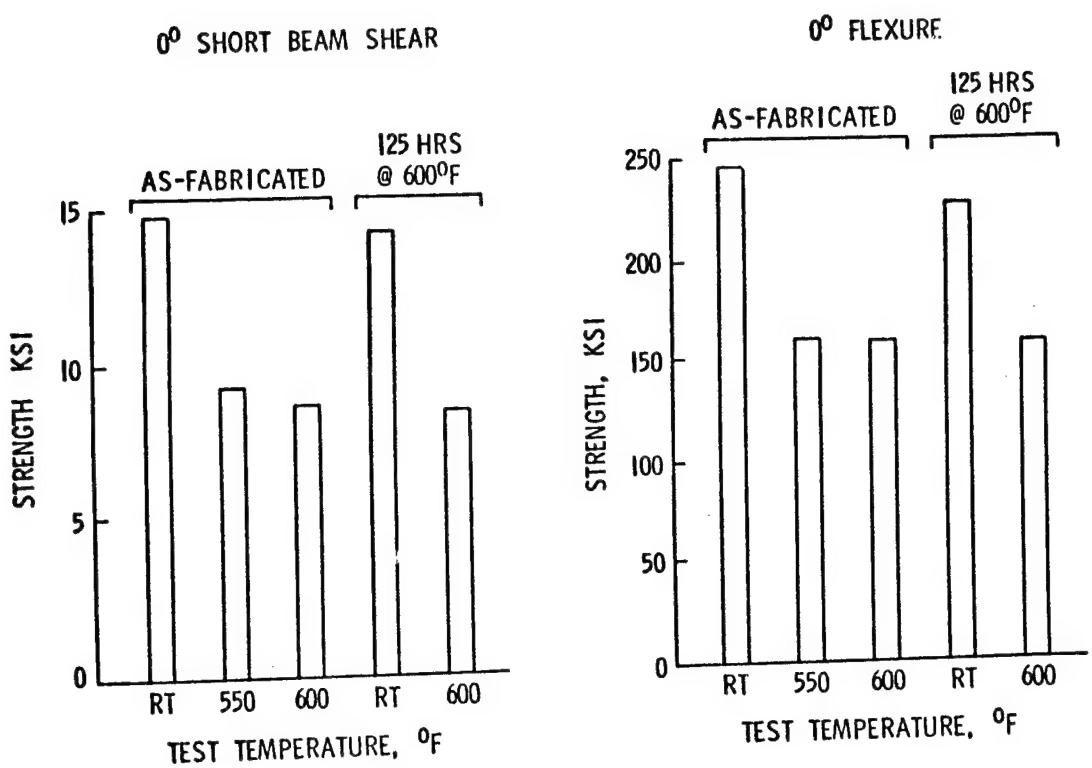
ADHESIVE

FM-34
LARC 13
~~NR150B2G~~
~~PPQ~~
~~A380~~
RTV 560-SQX

FIBER

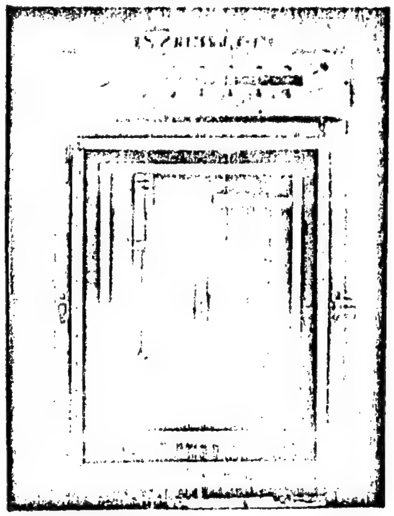
~~HTS1~~
~~MODMOR II~~
~~HTS 2~~
CELION
AS4

INFLUENCE OF ENVIRONMENT ON CELION 6000/PMR-15 STRENGTH



GRAPHITE/POLYIMIDE DESIGN ALLOWABLES FOR CASTS

TEST APPARATUS



SPECIMEN TYPES

- TENSION
- COMPRESSION
- SHEAR
- SCARF JOINTS
- BOLTED JOINTS
- FRACTURE
- FATIGUE
- DEBOND PROPAGATION

DATA OUTPUT

- STRESS-STRAIN CURVES
- FAILURE STRENGTHS
- MODULI
- POISSON'S RATIO
- FRACTURE TOUGHNESS
- FATIGUE STRENGTH
- FATIGUE LIFE
- DEBOND RATES

ENVIRONMENTS

- −250°F, RT, AND 600°F
- MOISTURE CONDITIONING
- THERMAL CYCLING

LAMINATE CONFIGURATIONS

0°, 90°, ±45°, AND $[0°, \pm 45°, 90°]_s$

SUBSEQUENT SPEAKERS

CHRIS CHAMIS - MATERIALS AND STRUCTURES DIVISION, LEWIS
"COMPOSITES FOR ENGINE APPLICATIONS"

BLAND STEIN - MATERIALS DIVISION, LANGLEY
"ENVIRONMENTAL EFFECTS ON COMPOSITES"

G. LARRY RODERICK - MATERIALS DIVISION, LANGLEY
"FATIGUE OF COMPOSITES"

JOHN R. DAVIDSON - MATERIALS DIVISION, LANGLEY
"FATIGUE OF JOINTS AND DAMAGE TOLERANCE IN COMPOSITES"

JAMES H. STARNES - STRUCTURES AND DYNAMICS DIVISION, LANGLEY
"ADVANCED COMPOSITE COMPRESSION STRUCTURES"

ENVIRONMENTAL EFFECTS ON COMPOSITES

BLAND A. STEIN
MATERIALS RESEARCH BRANCH
LANGLEY RESEARCH CENTER

USE OF WEATHER DATA TO PREDICT MOISTURE CONTENT IN RESIN MATRIX COMPOSITES

OBJECTIVE: TO PREDICT THE MOISTURE CONTENT IN FLIGHT SERVICE ENVIRONMENT

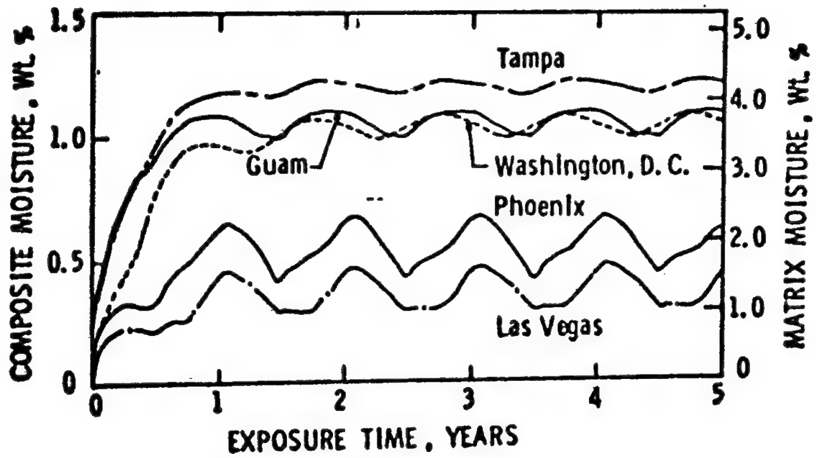
APPROACH:

- o SOLVE THE DIFFUSION EQUATION BY FINITE DIFFERENCE TECHNIQUE
  - o EFFECTIVE DIFFUSION COEFFICIENT OBTAINED FROM STATIC ABSORPTION/DESORPTION COUPON TESTS
  - o SURFACE CONCENTRATION ASSUMED PROPORTIONAL TO RELATIVE HUMIDITY OF ENVIRONMENT
- o WEATHER DATA DEFINES GROUND EXPOSURE CONDITIONS
- o USE AIRCRAFT UTILIZATION DATA TO DEFINE TYPICAL FLIGHT SCENARIOS FOR COMMERCIAL AIRCRAFT
- o USE SOLAR RADIATION DATA TO ESTIMATE EFFECTIVE TEMPERATURE

LARC ENVIRONMENTAL EFFECTS ON COMPOSITES RESEARCH

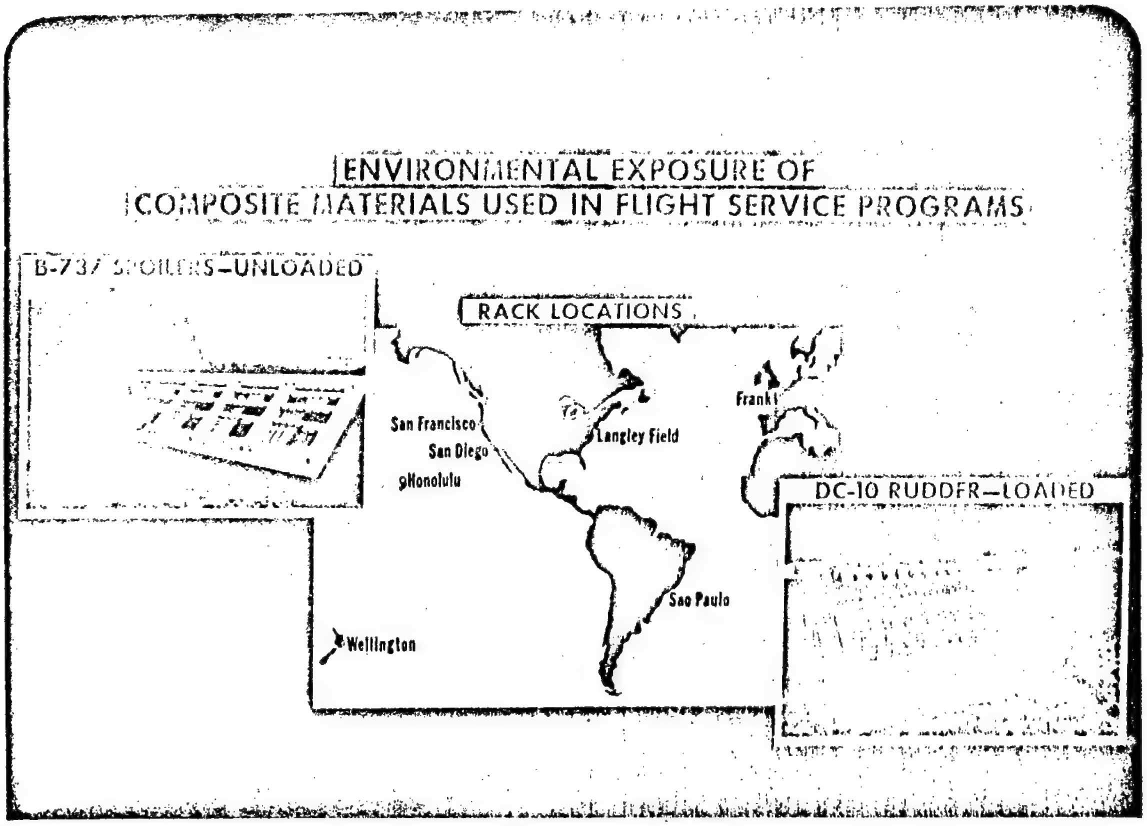
- o TYPICAL RESEARCH RATIONALE
- o PREDICTION OF MOISTURE ABSORPTION
  - o USE OF WEATHER DATA
  - o SOLAR HEATING EFFECTS
  - o SENSITIVITY TO DIFFUSION COEFFICIENTS
  - o COMPARISON WITH WORLDWIDE GROUND EXPOSURE DATA
- o ENVIRONMENTAL EXPOSURE EFFECTS FOR COMMERCIAL AIRCRAFT SERVICE
- o TIME-TEMPERATURE-STRESS TESTS OF COMPOSITES FOR SUPERSONIC CRUISE
- o ENVIRONMENTAL EXPOSURE EFFECTS FOR SPACE TRANSPORTATION SYSTEMS
- o DURABILITY OF COMPOSITES IN SPACE

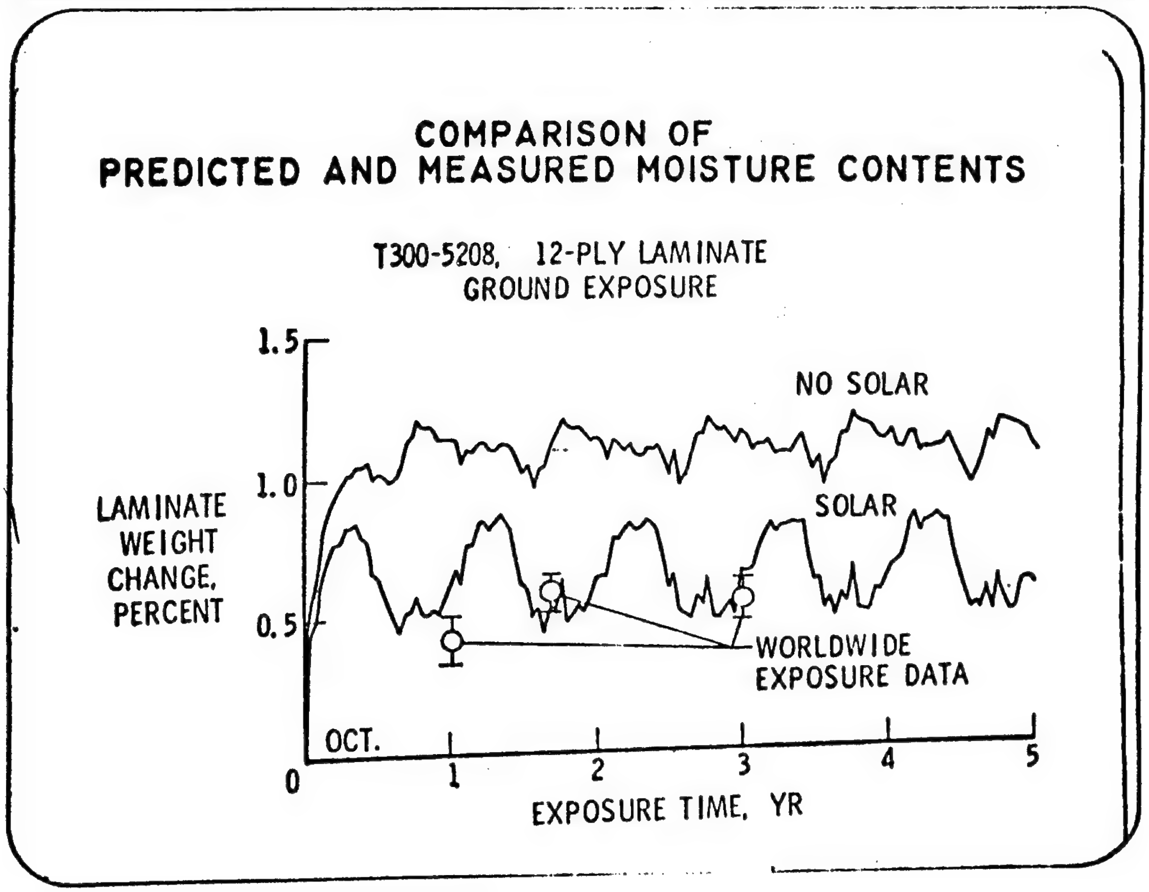
CALCULATED MOISTURE CONTENT FOR DIFFERENT GROUND STATIONS
T300/5208 24-Ply Laminate



ANALYTICAL RESULTS

- o REPORTED CHANGES IN D DUE TO CYCLIC WETTING AND DRYING RESULTS IN:
  - o NO SIGNIFICANT CHANGE IN AVERAGE MOISTURE CONTENT
  - o SIGNIFICANT CHANGE IN ABSORPTION - DESORPTION ZONE DEPTH
- o AVERAGE MOISTURE CONTENT INVERSELY RELATED TO SOLAR ABSORPTANCE
- o AVERAGE MOISTURE CONTENT DIRECTLY RELATED TO HEAT TRANSFER COEFFICIENT
- o VERTICAL PANEL ABSORBS ABOUT 15% MORE MOISTURE THAN A HORIZONTAL PANEL
- o AVERAGE MOISTURE CONTENT IS ABOUT THE SAME FOR ALL NON-DESERT LOCATIONS
- o SOLAR EXPOSURE DECREASES AVERAGE MOISTURE CONTENT BY ABOUT 25% REGARDLESS OF LOCATION


ENVIRONMENTAL EXPOSURE OF
COMPOSITE MATERIALS USED IN FLIGHT SERVICE PROGRAMS
B-737 SPOILERS—UNLOADED
RACK LOCATIONS
San Francisco
San Diego
Honolulu
Langley Field
DC-10 RUDDER—LOADED
Sao Paulo
Wellington


COMPARISON OF
PREDICTED AND MEASURED MOISTURE CONTENTS
T300-5208, 12-PLY LAMINATE
GROUND EXPOSURE
LAMINATE WEIGHT CHANGE, PERCENT
1.5
1.0
0.5
0
NO SOLAR
SOLAR
WORLDWIDE EXPOSURE DATA
OCT.
1
2
3
4
5
EXPOSURE TIME, YR

SUMMARY

- o THE ABSORPTION/DESORPTION BEHAVIOR OF RESIN MATRIX COMPOSITES CAN BE ADEQUATELY DESCRIBED BY DIFFUSION THEORY
- o MOISTURE CONTENT CAN BE PREDICTED FROM MONTHLY OR YEARLY AVERAGED WEATHER DATA
- o T300/5208 COMPOSITE REACHES AN EQUILIBRIUM MOISTURE LEVEL OF APPROXIMATELY 1 WT.% WHEN EXPOSED AT DIFFERENT LOCATIONS AROUND THE U. S.
- o FLIGHT SERVICE RETARDS MOISTURE PICK-UP AND MAY LOWER THE EQUILIBRIUM MOISTURE CONTENT BY 10 TO 20%
- o SOLAR HEATING MAY LOWER THE EQUILIBRIUM MOISTURE CONTENT BY AS MUCH AS 25%

ENVIRONMENTAL EXPOSURE EFFECTS ON COMPOSITES FOR COMMERCIAL AIRCRAFT - CONTRACT NAS1-15148
BOEING COMMERCIAL AIRPLANE COMPANY

OBJECTIVES

- o DEFINE EFFECTS OF LONG-TERM EXPOSURE TO MOISTURE ON THE MECHANICAL PROPERTIES OF COMPOSITE MATERIALS
- o ESTABLISH METHODS FOR ACCELERATED ENVIRONMENTAL TESTING
- o DEVELOP MATH MODEL TO PREDICT LONG-TERM PERFORMANCE OF COMPOSITES

MATERIALS

NARMCO-T300/5208, FIBERITE-T300/1034, NARMCO-T300/5209

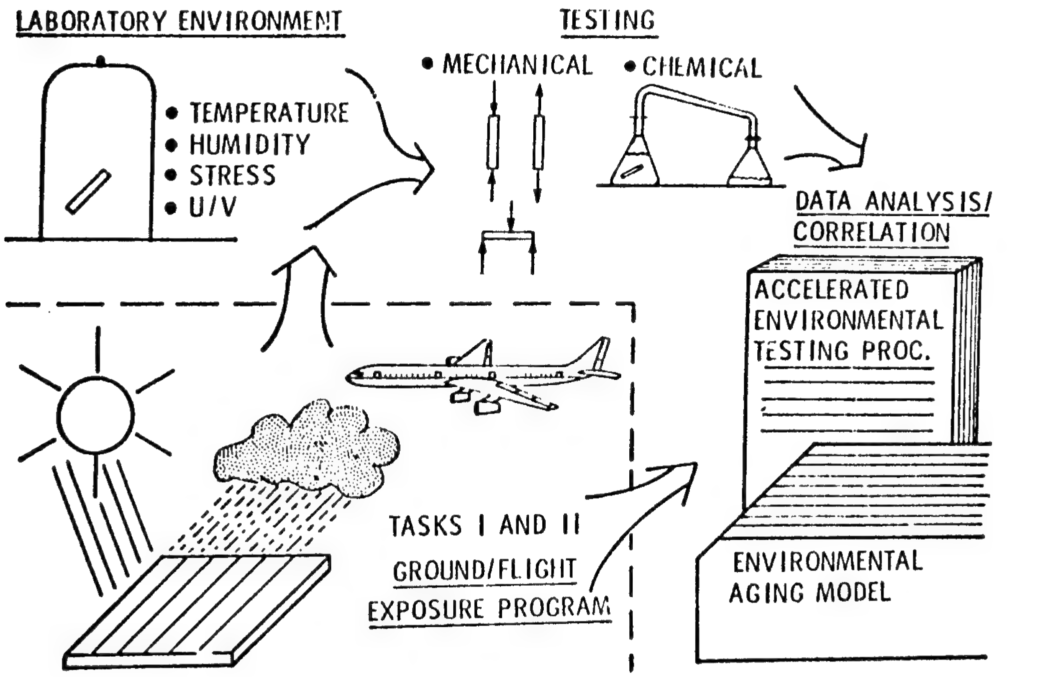
TASKS

I. FLIGHT EXPOSURE: 3 AIRLINES - INTERIOR AND EXTERIOR SPECS - 10 YEARS

II. GROUND EXPOSURE: 4 SITES - LOADED AND UNLOADED SPECS - 10 YEARS

III. ACCELERATED ENVIRONMENTAL EFFECTS AND DATA CORRELATION: LAB EXPOSURE - CORRELATE RESULTS - IDENTIFY ACCELERATED TESTING PROCEDURES - DEVELOP MATH MODEL

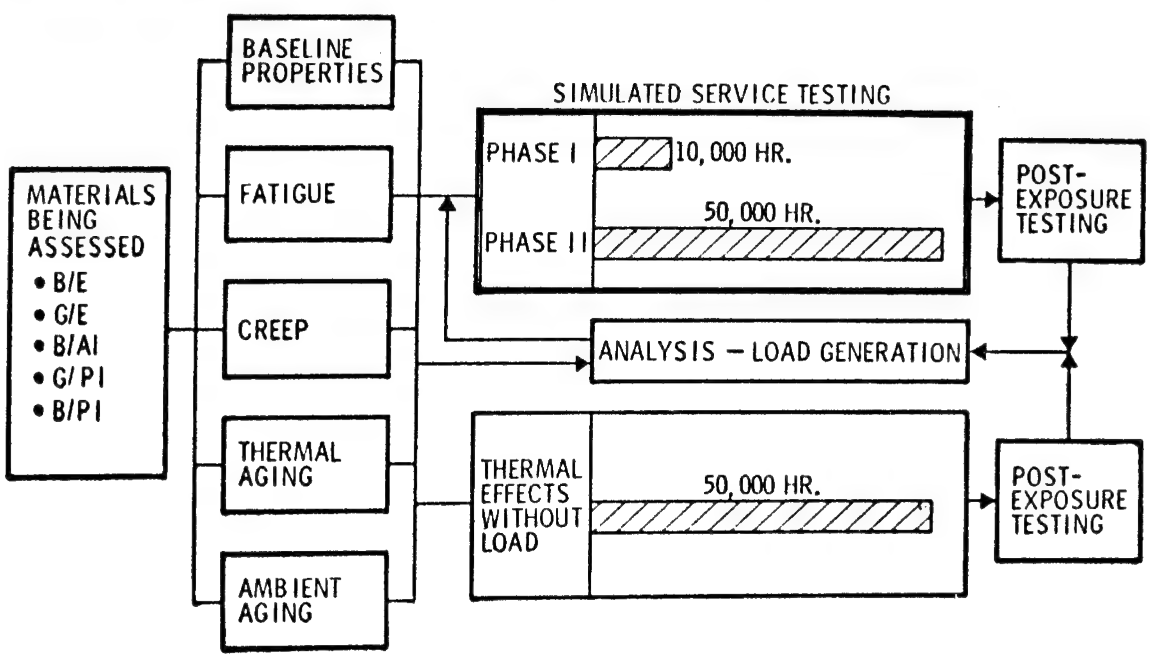
TASK III – ACCELERATED ENVIRONMENTAL EFFECTS AND DATA CORRELATION



TIME-TEMPERATURE-STRESS CAPABILITIES OF COMPOSITE MATERIALS

GENERAL DYNAMICS
Convair Aerospace Division

Advanced Supersonic Technology Applications – Contract NAS 1-12308



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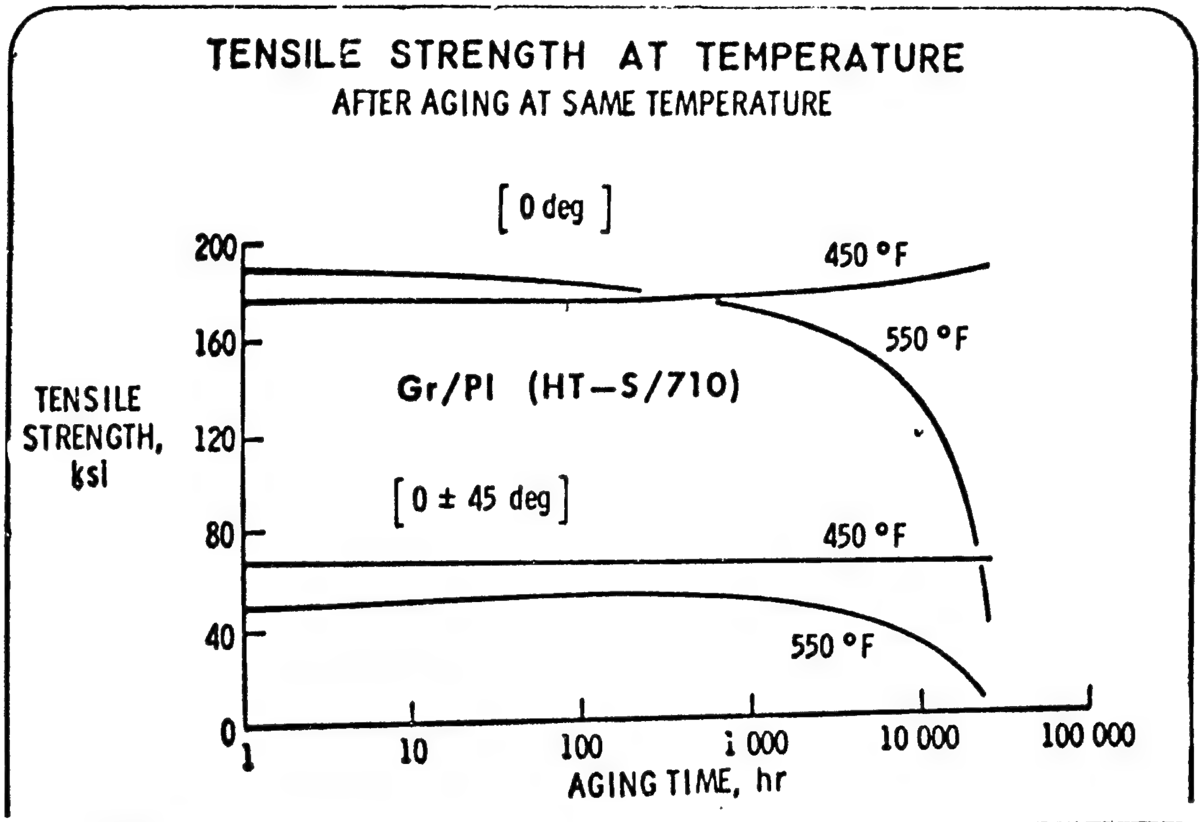
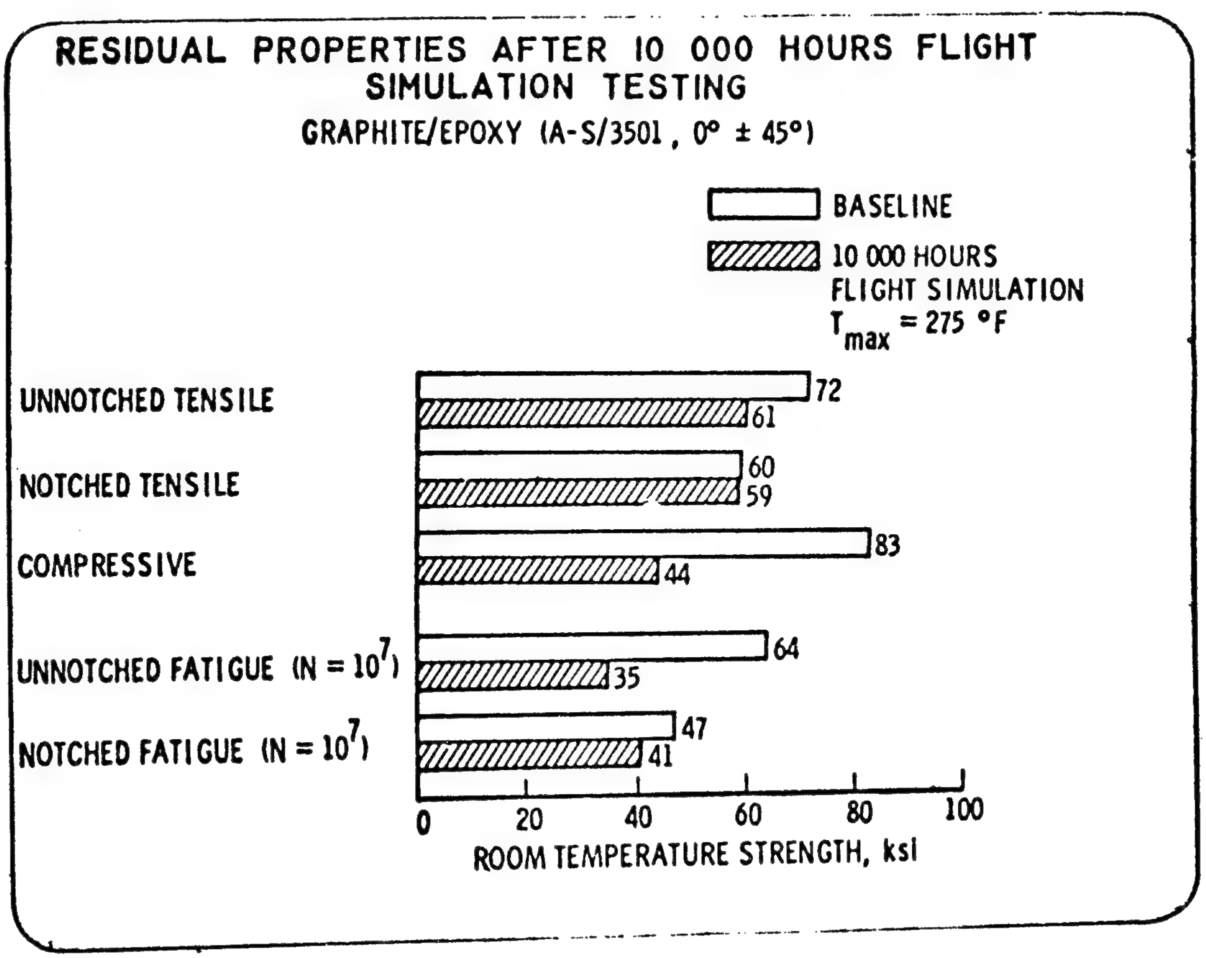




NASA-Langley, Form 92 (APR 69)

TIME - TEMPERATURE - STRESS CAPABILITIES OF COMPOSITES FOR SUPERSONIC CRUISE AIRCRAFT

INTERIM CONCLUSIONS

GRAPHITE/EPOXY (A-S/3501) AND BORON/EPOXY (5505) LIMITED TO <394K (250°F) FOR EXPOSURES >10,000 HOURS BECAUSE OF

- MOISTURE EFFECTS ON ELEVATED TEMPERATURE STRENGTH (MATRIX DEGRADATION)
- LOSS OF RESIDUAL TENSILE STRENGTH DURING THERMAL AGING (OXIDATION INDUCED MATRIX DEGRADATION)
- EARLY FLIGHT SIMULATION TEST FAILURES (COMPRESSION LOAD/OXIDATION INDUCED MATRIX DEGRADATION)

TIME - TEMPERATURE - STRESS CAPABILITIES OF COMPOSITES FOR SUPERSONIC CRUISE AIRCRAFT

INTERIM CONCLUSIONS (CONTINUED)

BORON/ALUMINUM (B/6061) LIMITED TO 450K (350°F) FOR EXPOSURES > 10,000 HOURS BECAUSE OF

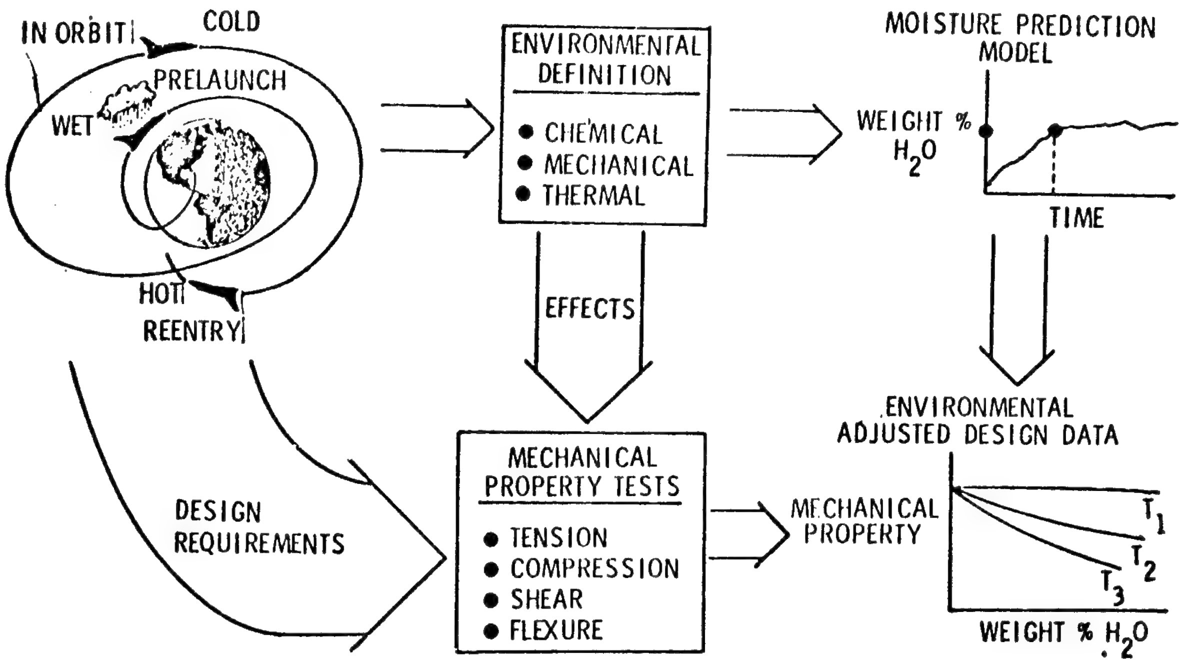
- LOSS OF RESIDUAL TENSILE STRENGTH DURING THERMAL AGING (INTERFACE DIFFUSION INDUCED FIBER DEGRADATION)
- HIGH TEMPERATURE FATIGUE EFFECTS (MATRIX SURFACE CRACKING/OXIDATION)

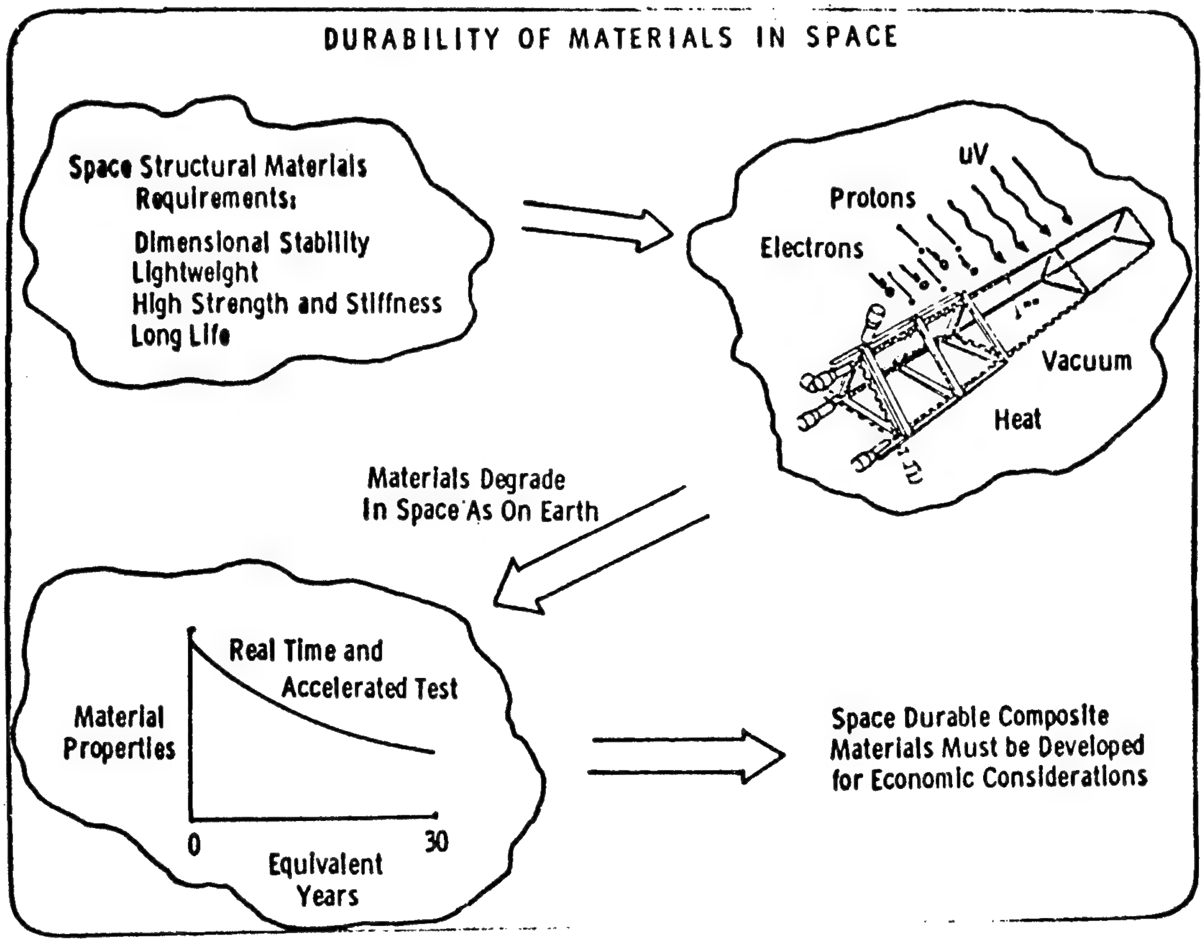
BORON/POLYIMIDE (B/P105A) NOT SUITABLE FOR THIS APPLICATION. (LACK OF THERMAL EXPOSURE STABILITY IN MATRIX FOR 1000 HOURS AT 505K (450°F))

GRAPHITE/POLYIMIDE (HT-S/710) LIMITED TO 505K (450°F) FOR EXPOSURES >10,000 HOURS BECAUSE OF

- LOSS OF RESIDUAL TENSILE STRENGTH DURING THERMAL AGING (OXIDATION INDUCED MATRIX DEGRADATION)

CASTS ENVIRONMENTAL EFFECTS PROGRAM





SUMMARY OF
LARC ENVIRONMENTAL EFFECTS ON COMPOSITES RESEARCH

- A RANGE OF NASA INTERESTS COVERED
  - COMMERCIAL AIRCRAFT SERVICE
  - SUPERSONIC CRUISE APPLICATIONS
  - ADVANCED SPACE TRANSPORTATION
  - LARGE SPACE STRUCTURES
- SIGNIFICANT ACCOMPLISHMENTS HAVE BEEN MADE
  - PREDICTION OF MOISTURE ABSORPTION IN SERVICE
  - MEASUREMENTS OF MOISTURE ABSORPTION IN U.S. AND OVERSEAS
  - TIME-TEMPERATURE LIMITATIONS FOR COMPOSITES IN LONG TERM SUPERSONIC CRUISE SERVICE SUGGESTED

FATIGUE OF COMPOSITES

I. COMPOSITE-REINFORCED METALS

II. LAMINATED COMPOSITES

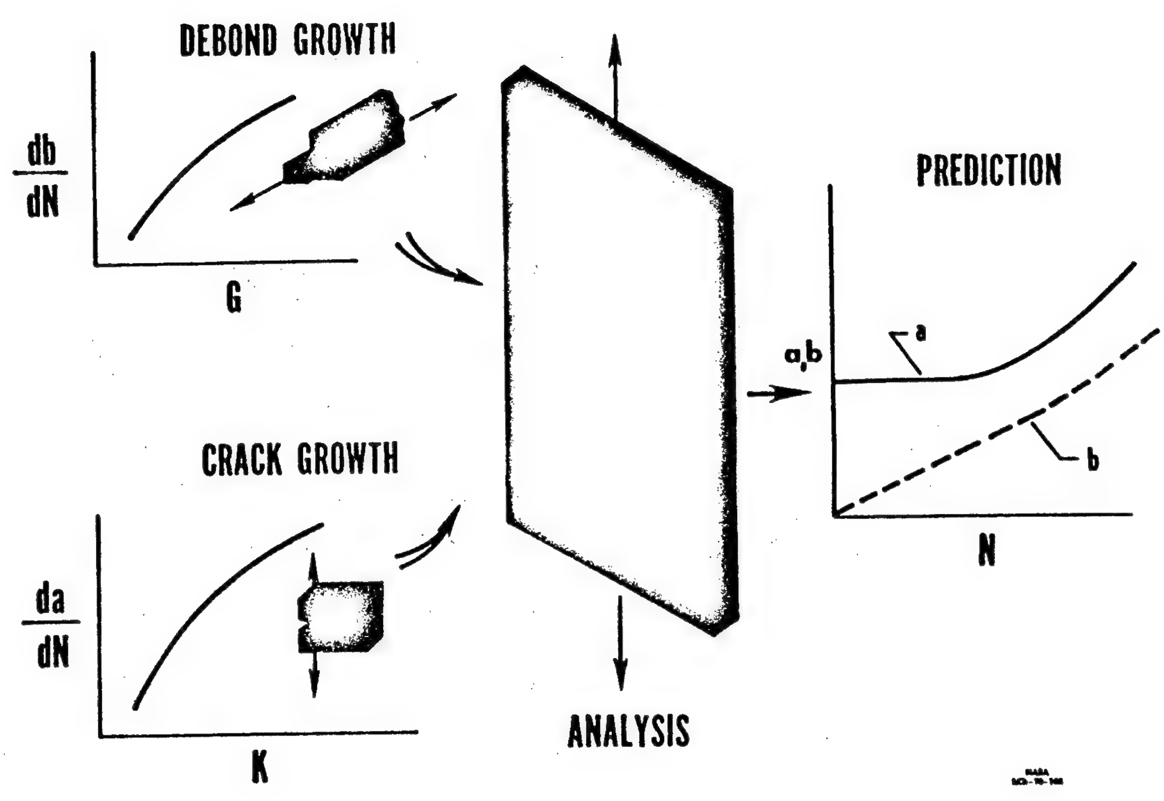
A. ENVIRONMENT

B. COMPRESSION

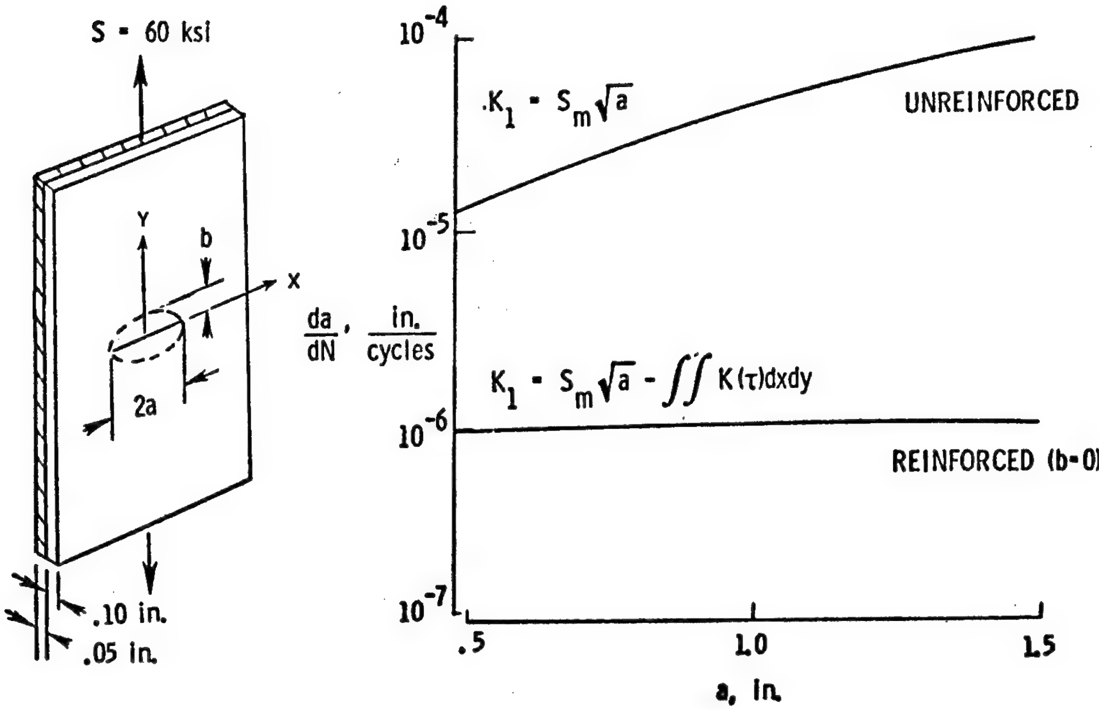
C. ANALYSIS

G. L. Roderick (USARTL)
Structural Integrity Branch
Langley Research Center

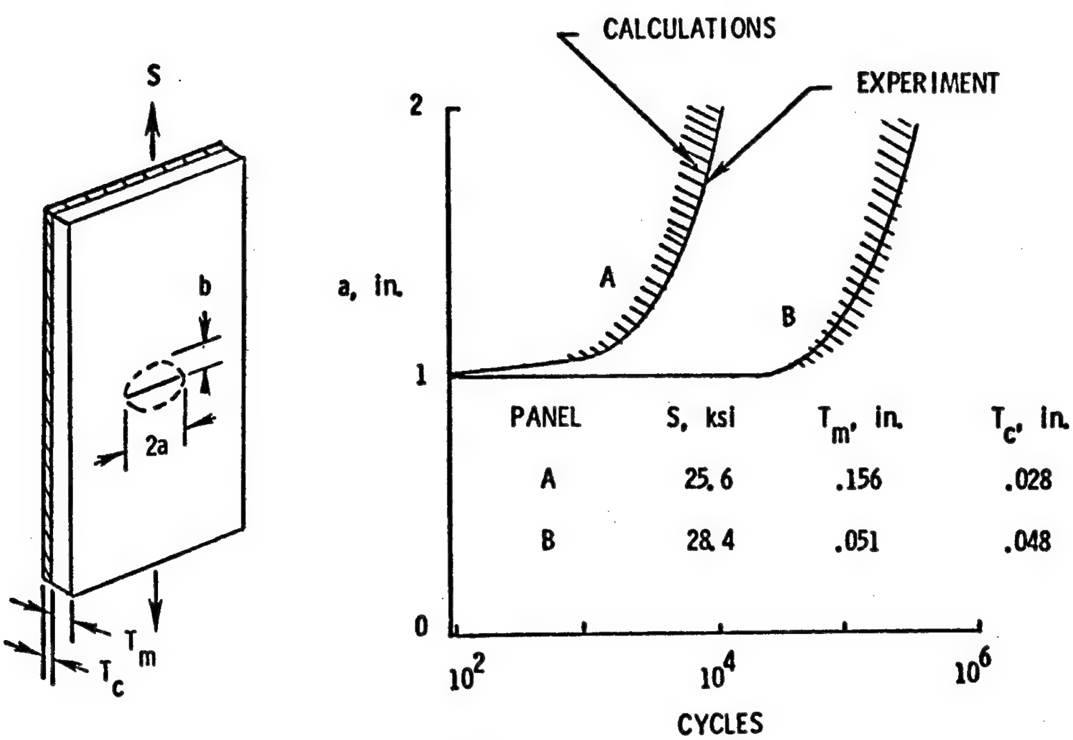
FATIGUE ANALYSIS OF REINFORCED METALS



CRACK GROWTH PREDICTION

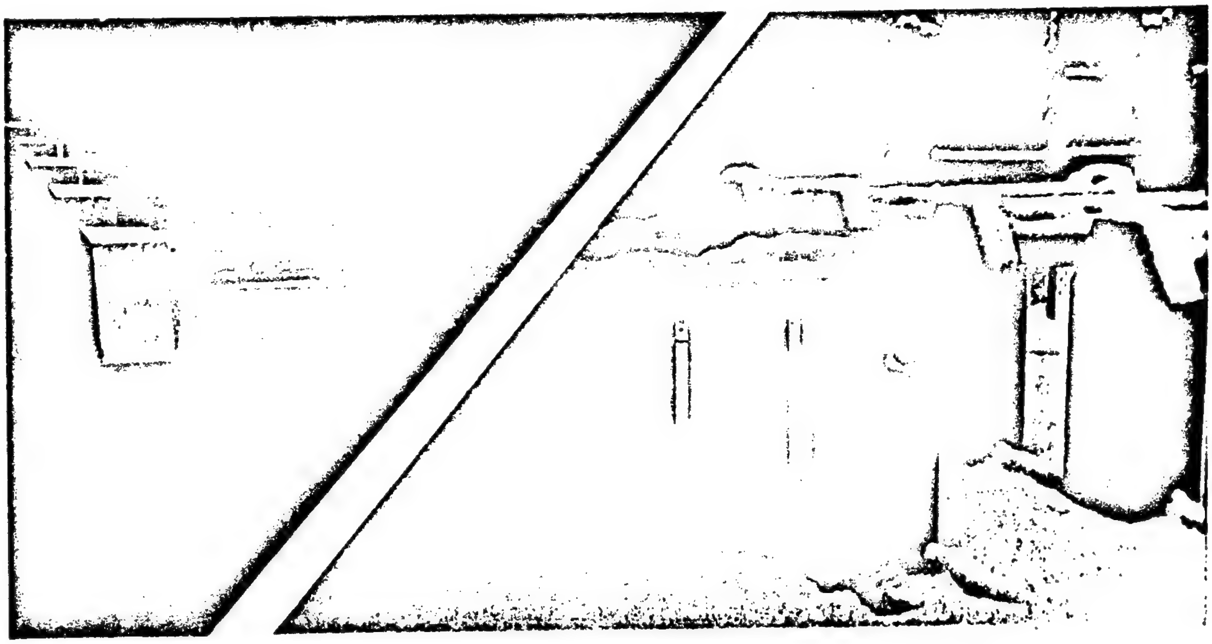


EXPERIMENTS CONFIRM ANALYSIS



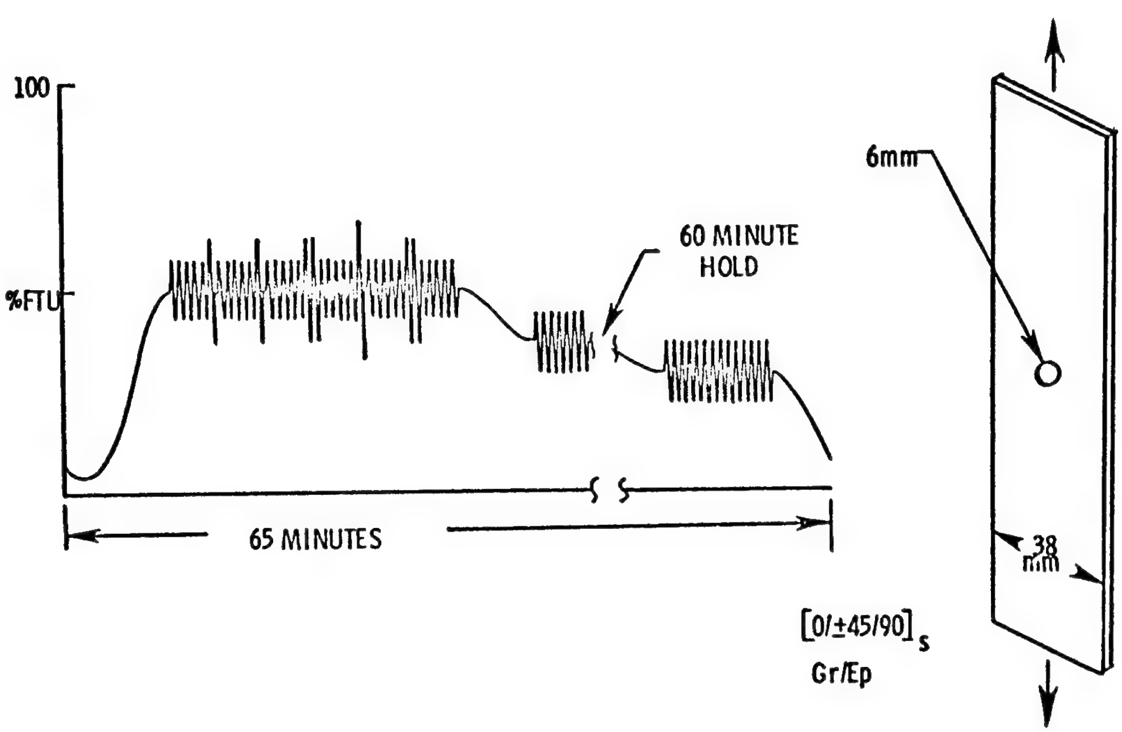
PANEL	S, ksi	T_m, in.	T_c, in.
A	25.6	.156	.028
B	28.4	.051	.048

ENVIROMENTAL FATIGUE TESTS ON COMPOSITES

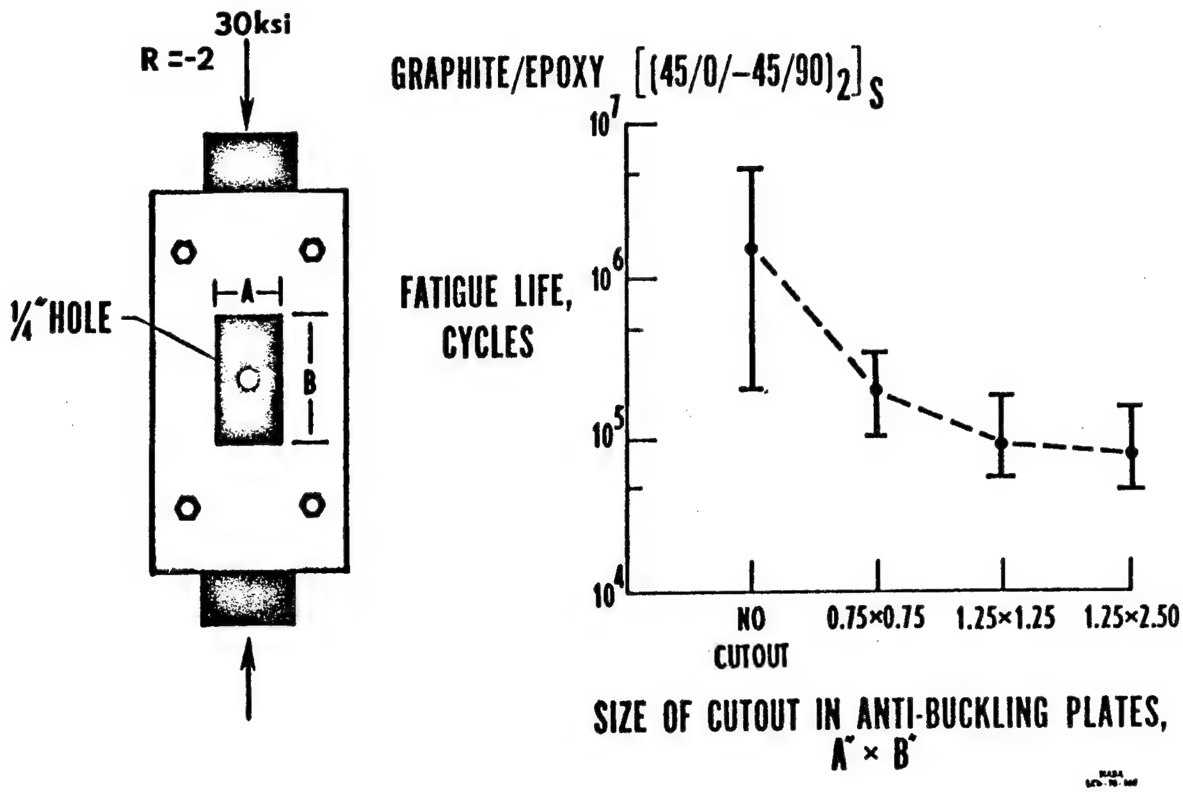


OUTDOOR FATIGUE TEST

FLIGHT SPECTRUM - SPECIMEN CONFIGURATION



EFFECT OF LOCAL BUCKLING CONSTRAINT ON COMPRESSION FATIGUE LIFE



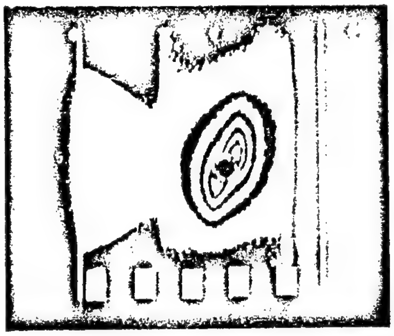
DEVELOPMENT OF FATIGUE ANALYSES

I. IDENTIFY FATIGUE FAILURE PROCESSES

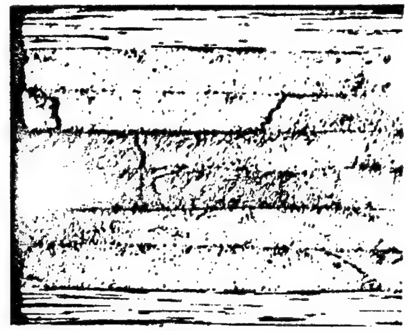
II. STUDY ELEMENTS OF THE FAILURE PROCESSES

III. DEVELOP ANALYSES

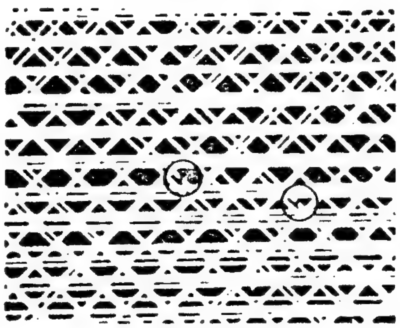
MONITORING FATIGUE DAMAGE



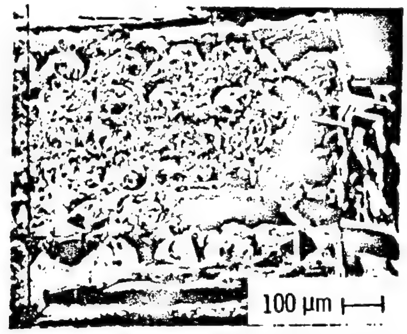
THERMOGRAPHY



METALLOGRAPHY



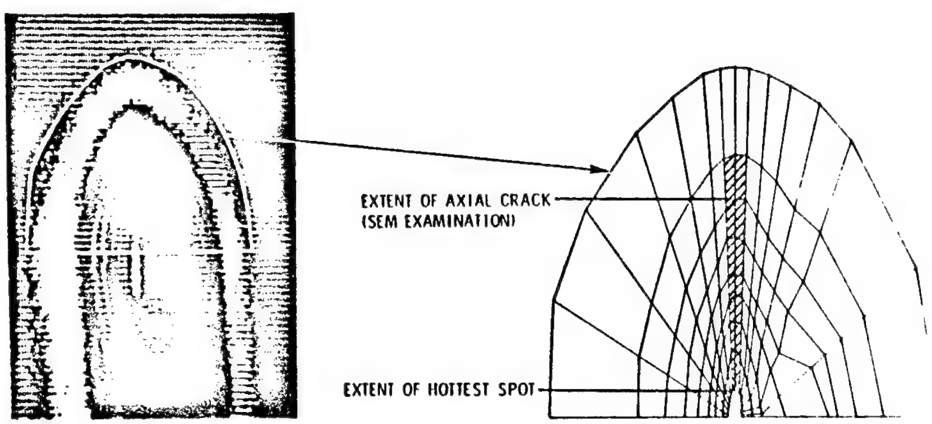
RADIOGRAPHY



SCANNING ELECTRON MICROSCOPY

CRACK LENGTH vs. CALCULATED HEAT GENERATION

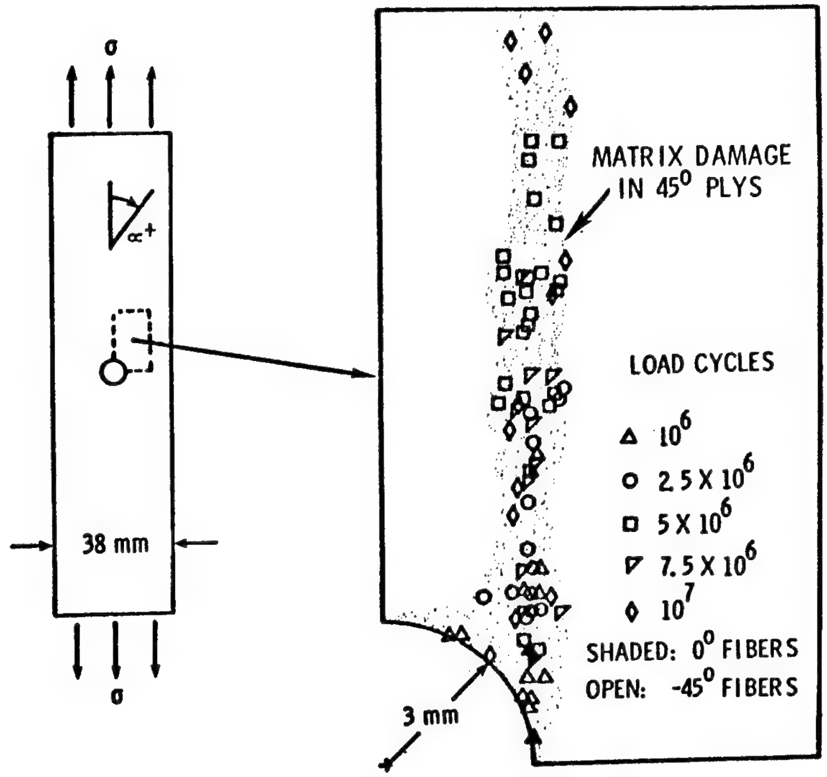
(0_8) SPECIMEN



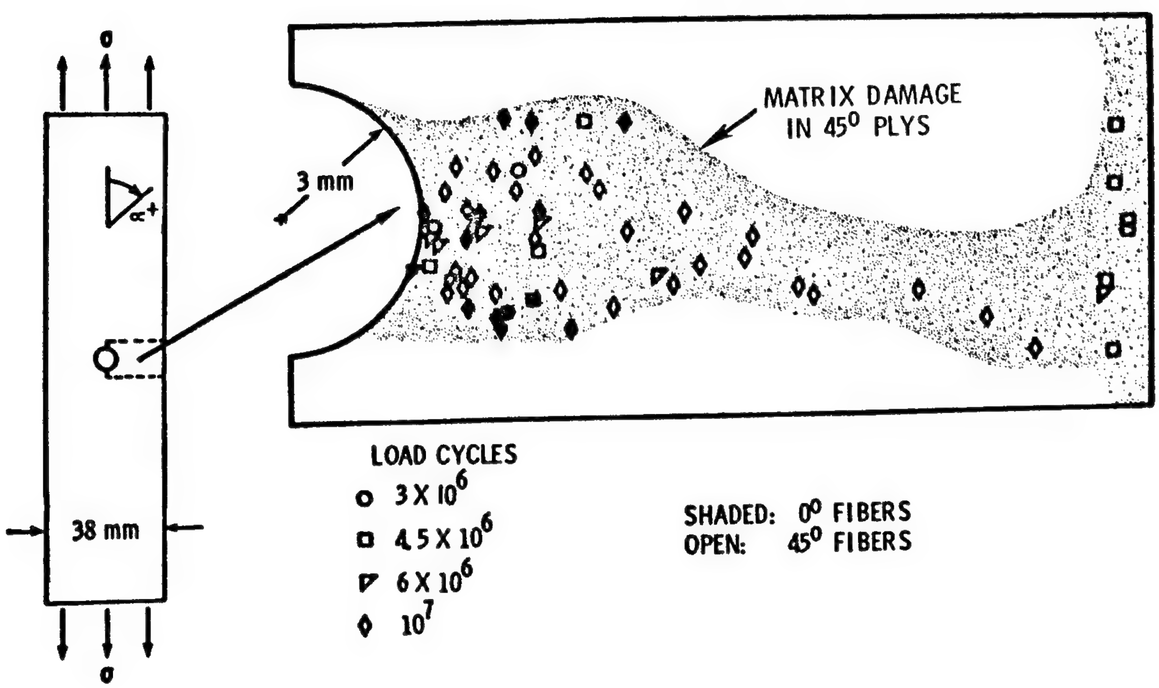
(a) THERMOGRAM

(b) FINITE ELEMENT MESH

FIBER FAILURES IN BORON-EPOXY LAMINATES UNDER CYCLIC LOADING (45/0/-45/0)$_S$

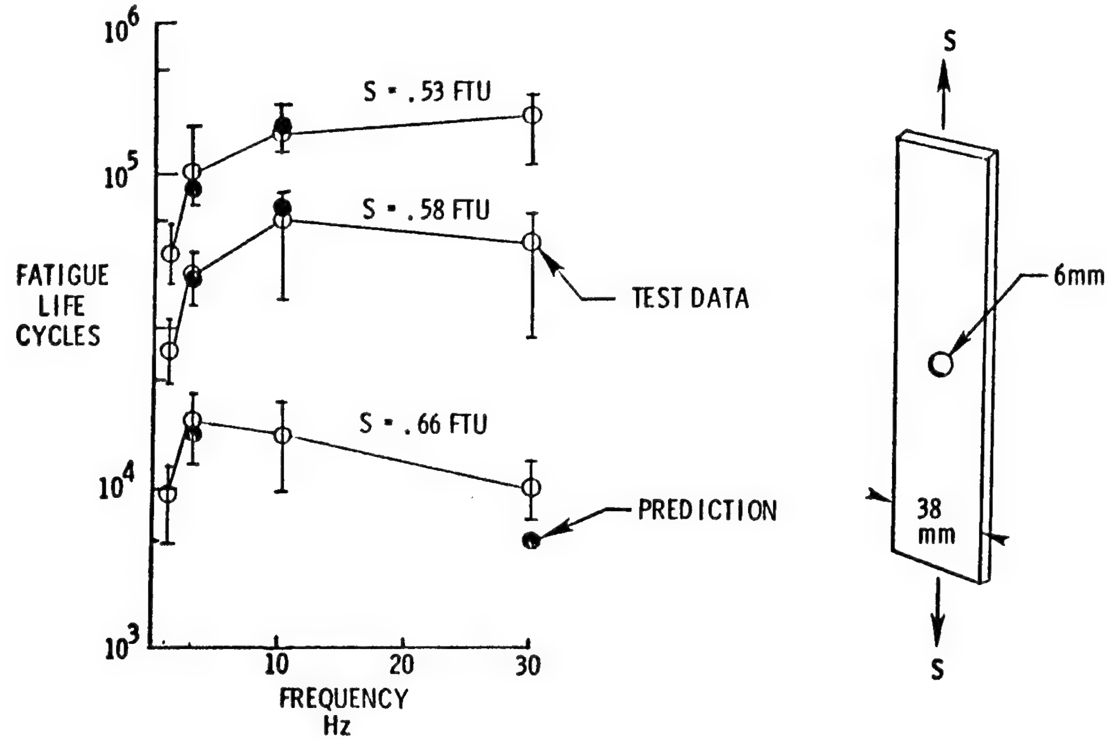


FIBER FAILURES IN BORON-EPOXY LAMINATES UNDER CYCLIC LOADING (45/90/-45/0)$_S$



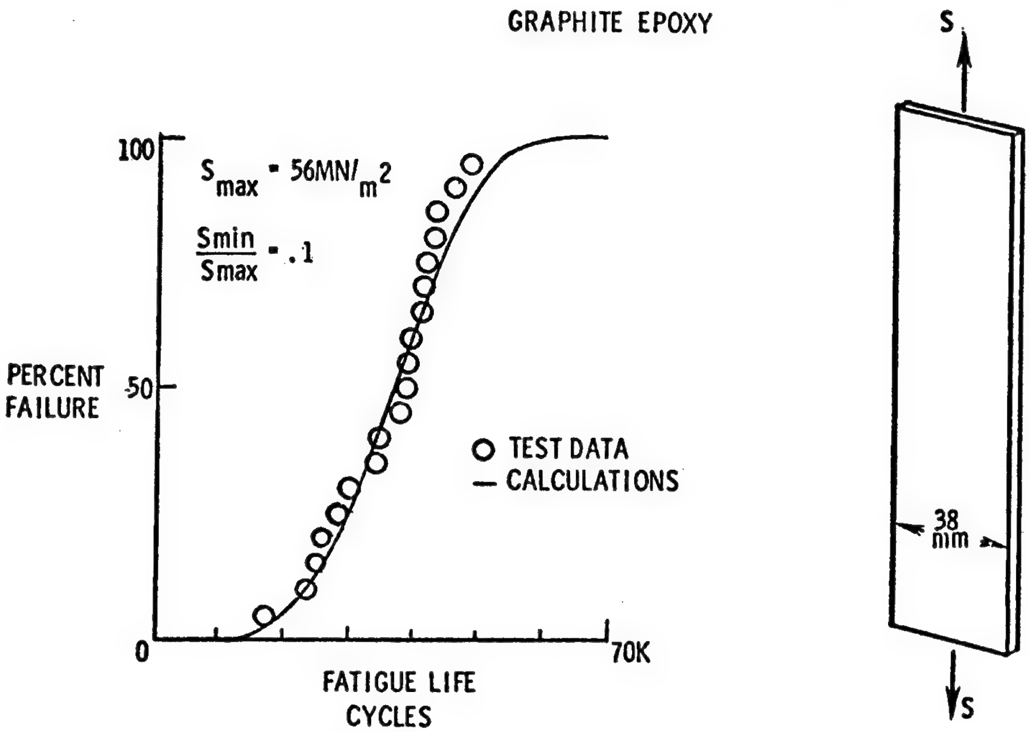
EFFECT OF FREQUENCY ON FATIGUE LIFE

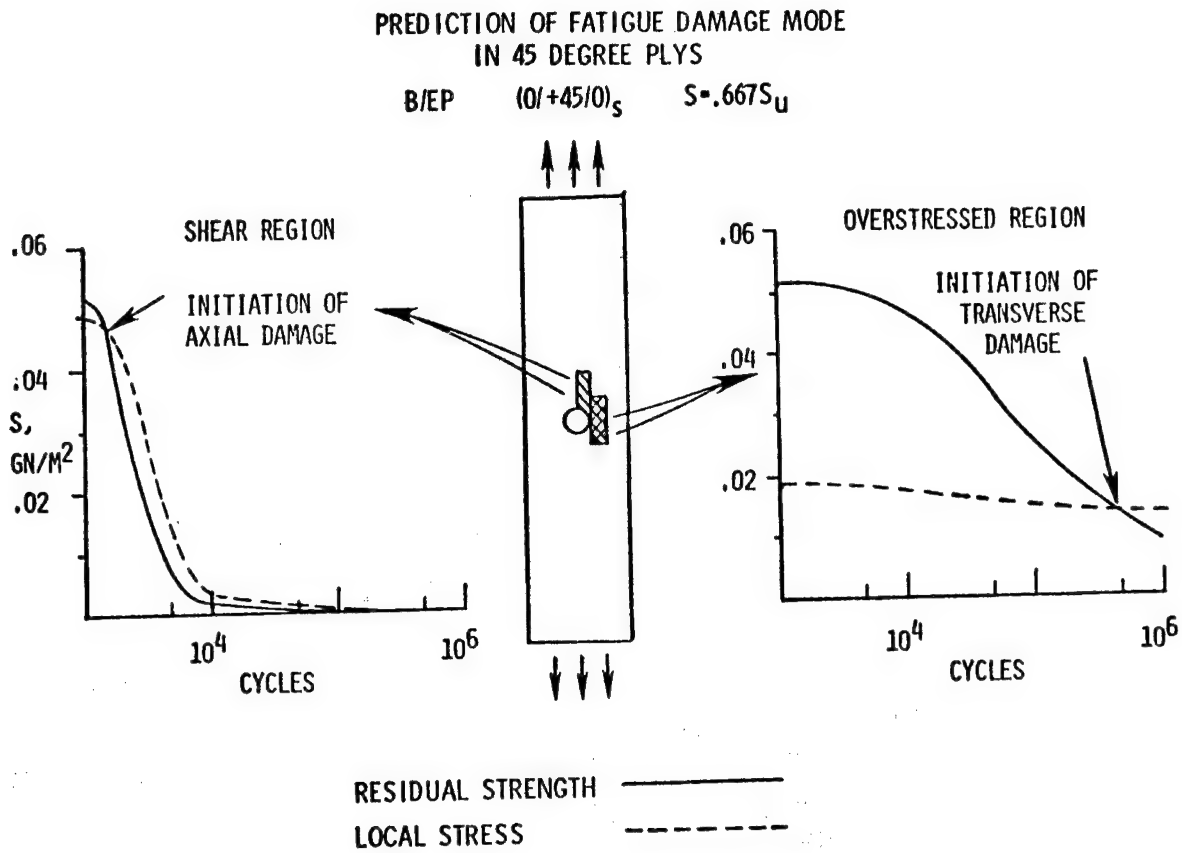
$(\pm 45_2)_s$ NOTCHED Gr/Ep



PREDICTION OF FATIGUE LIFE FOR $(\pm 45_2)_s$

GRAPHITE EPOXY




PREDICTION OF FATIGUE DAMAGE MODE
IN 45 DEGREE PLYS
B/EP
(0/+45/0)$_S$
S=.667S$_u$
SHEAR REGION
INITIATION OF
AXIAL DAMAGE
.06
.04
S,
GN/M^2
.02
10^4
10^6
CYCLES
OVERSTRESSED REGION
INITIATION OF
TRANSVERSE
DAMAGE
.06
.04
.02
10^4
10^6
CYCLES
RESIDUAL STRENGTH
LOCAL STRESS

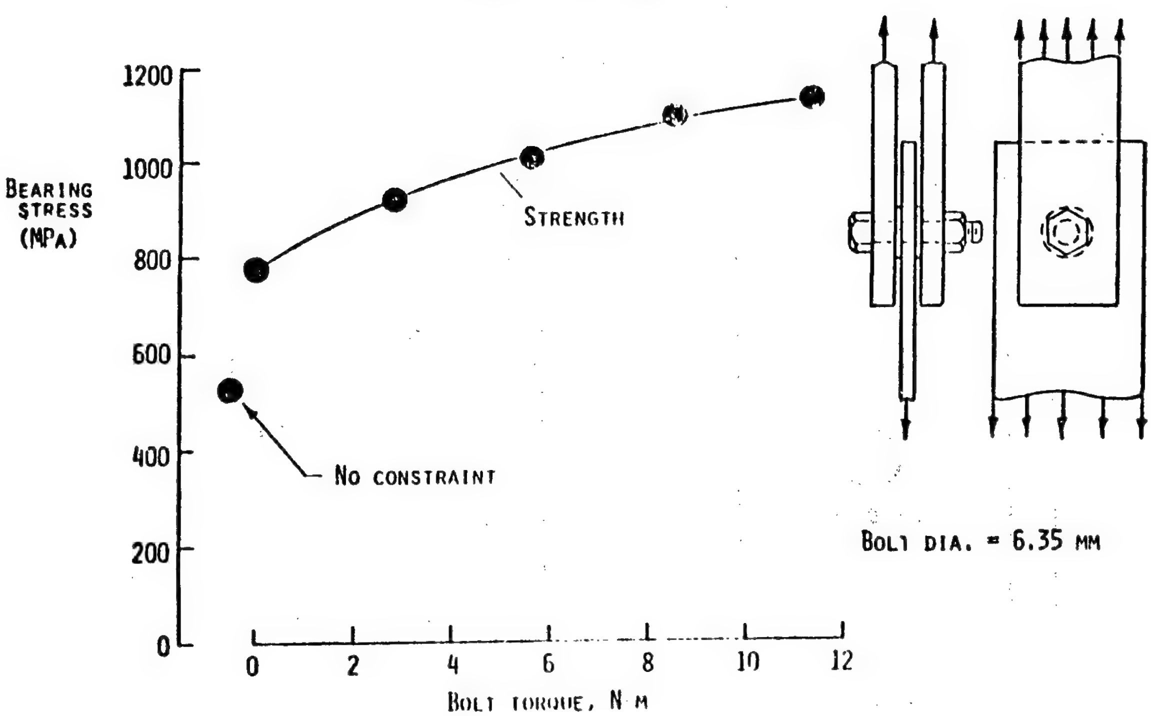
FATIGUE OF JOINTS AND

DAMAGE TOLERANCE IN COMPOSITES

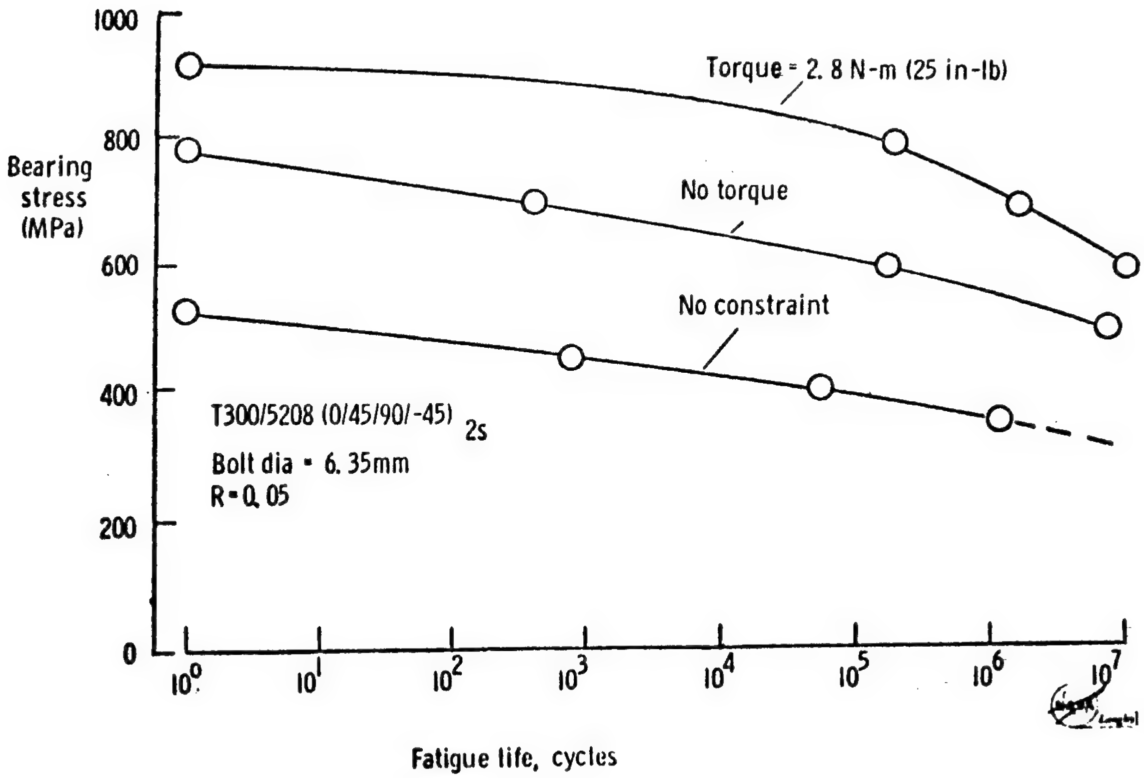
J. R. Davidson
Structural Integrity Branch
Langley Research Center

MECHANICALLY FASTENED JOINTS

STATIC BEARING STRENGTH
T300/5208 GRAPHITE-EPOXY
$(0/45/90/-45)_{2s}$

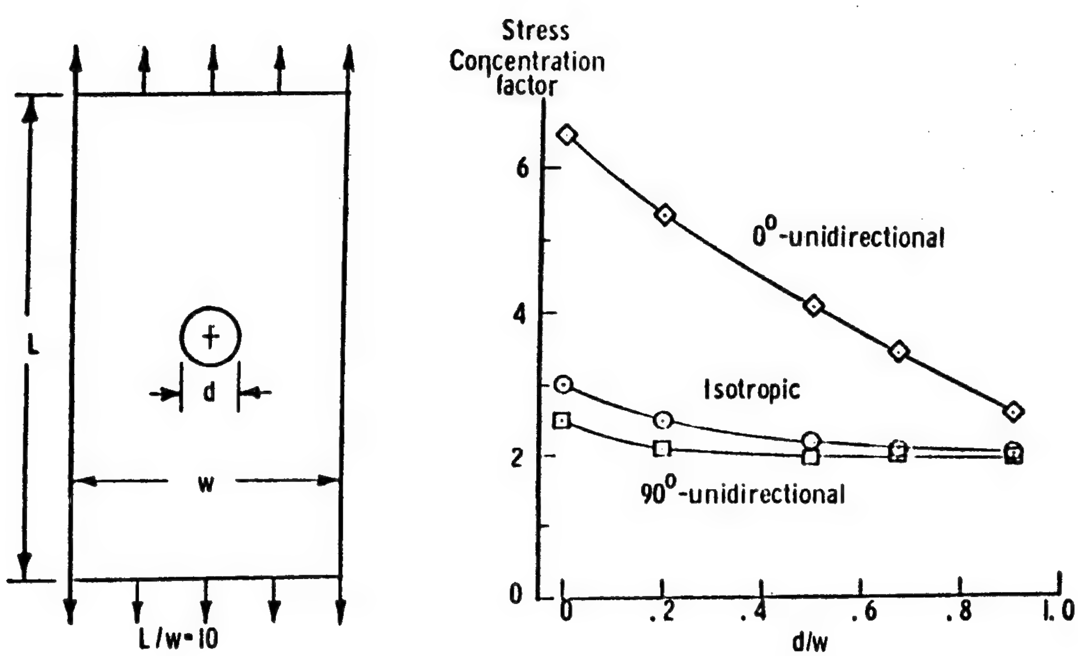


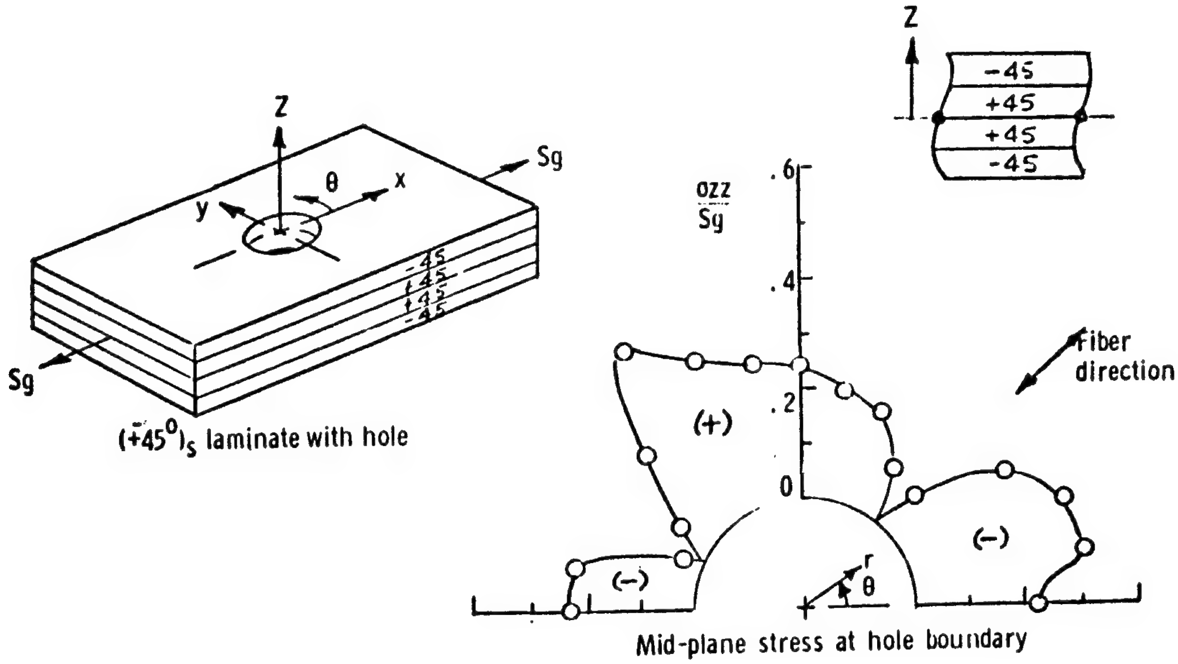
BEARING STRESS S-N CURVES



STRESS CONCENTRATIONS IN FINITE SHEETS

(T300/5208)





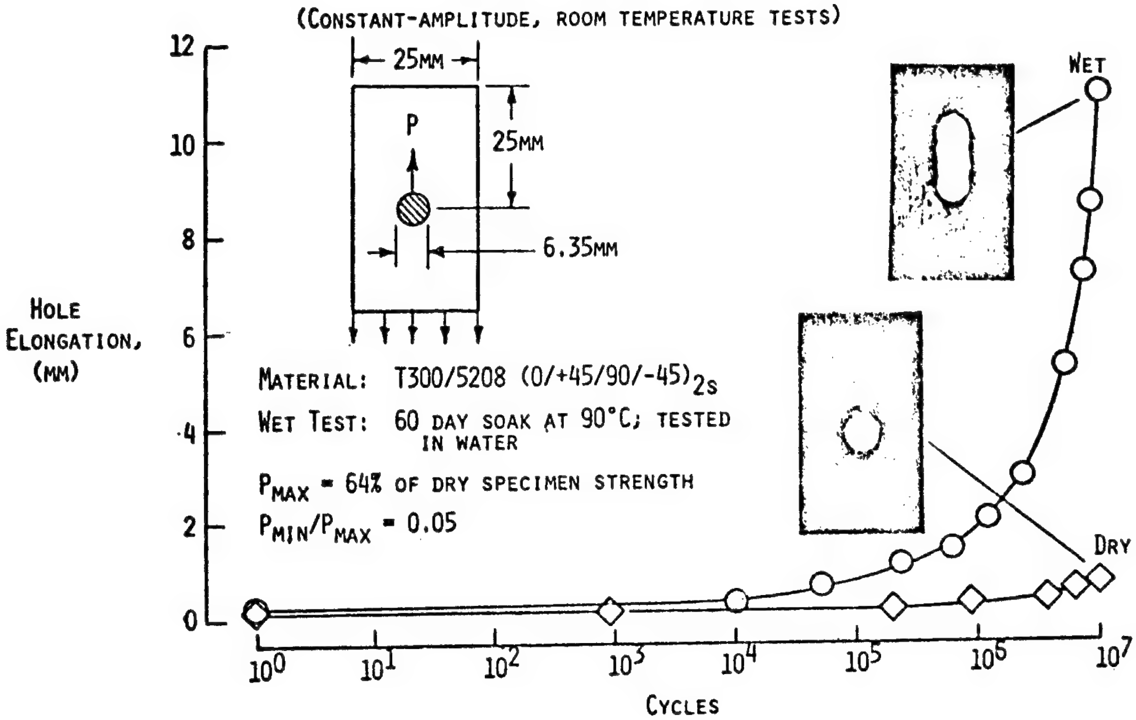
$(\mp 45^0)_s$ laminate with hole

Mid-plane stress at hole boundary

CYCLIC BEARING LOADS ELONGATE BOLT HOLES

COMPARISON OF WET AND DRY GRAPHITE/EPOXY

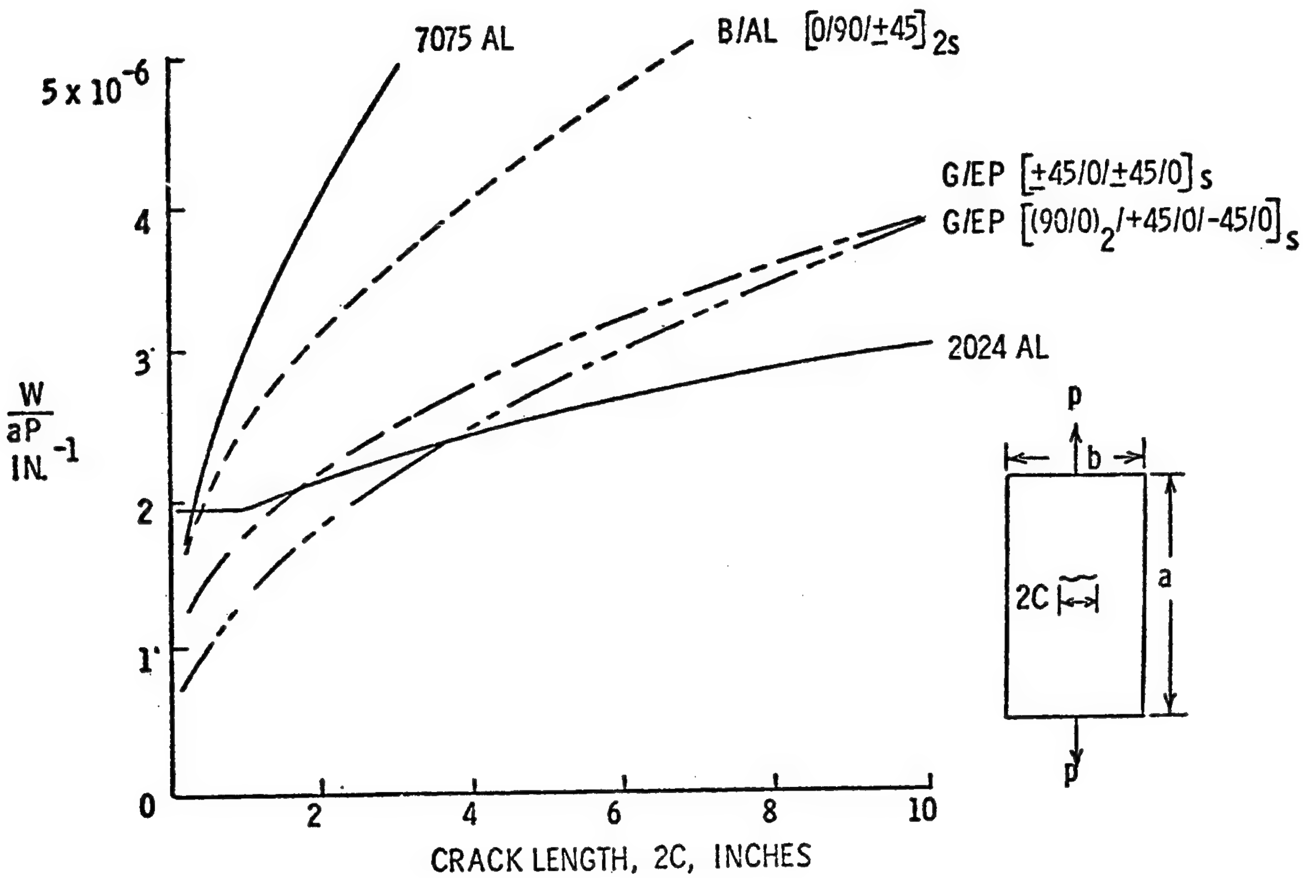
(CONSTANT-AMPLITUDE, ROOM TEMPERATURE TESTS)



FRACTURE AND

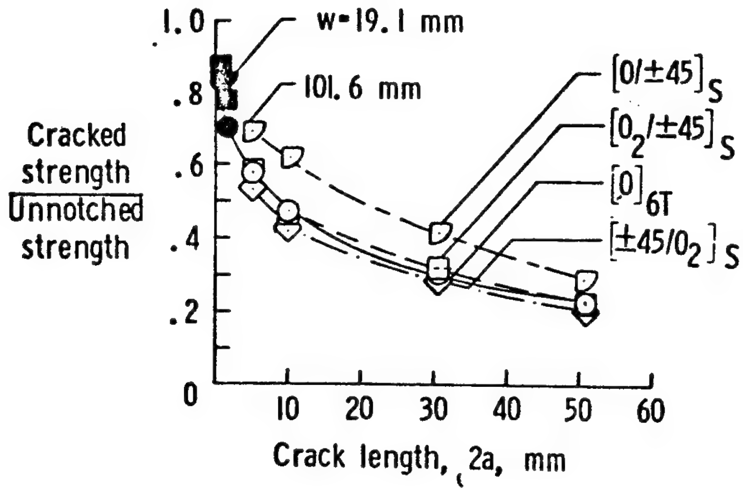
DAMAGE TOLERANCE

WEIGHT INDEX FOR TENSION PANELS



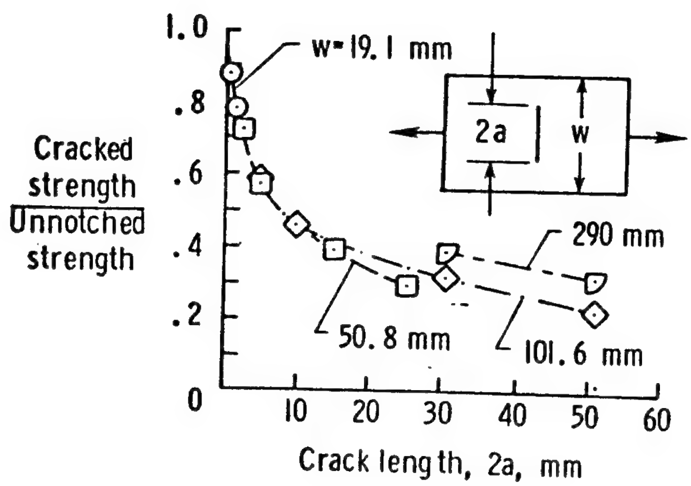
FRACTURE OF B/AL LAMINATES

Effect of Laminate Orientation on Cracked Strength



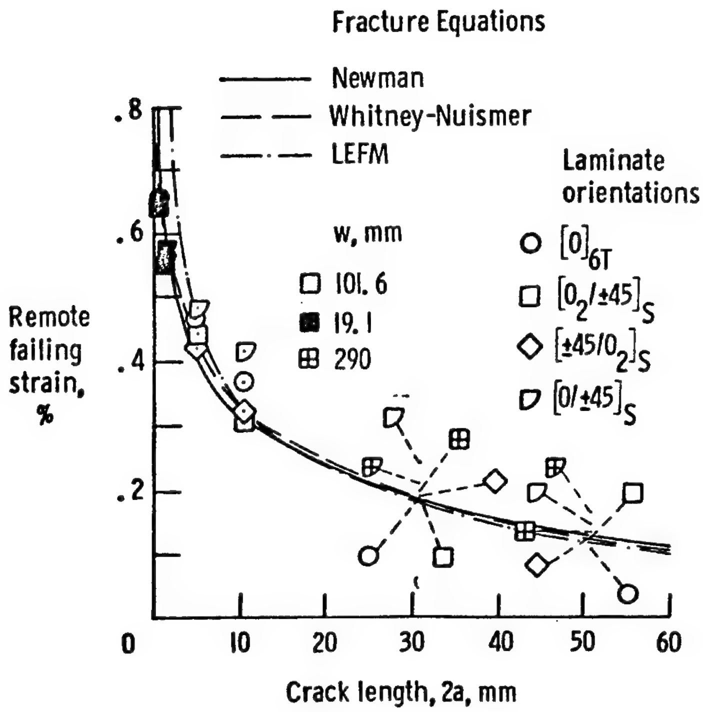
FRACTURE OF B/AL LAMINATES

Effect of specimen width, $[0_2/\pm45]_S$

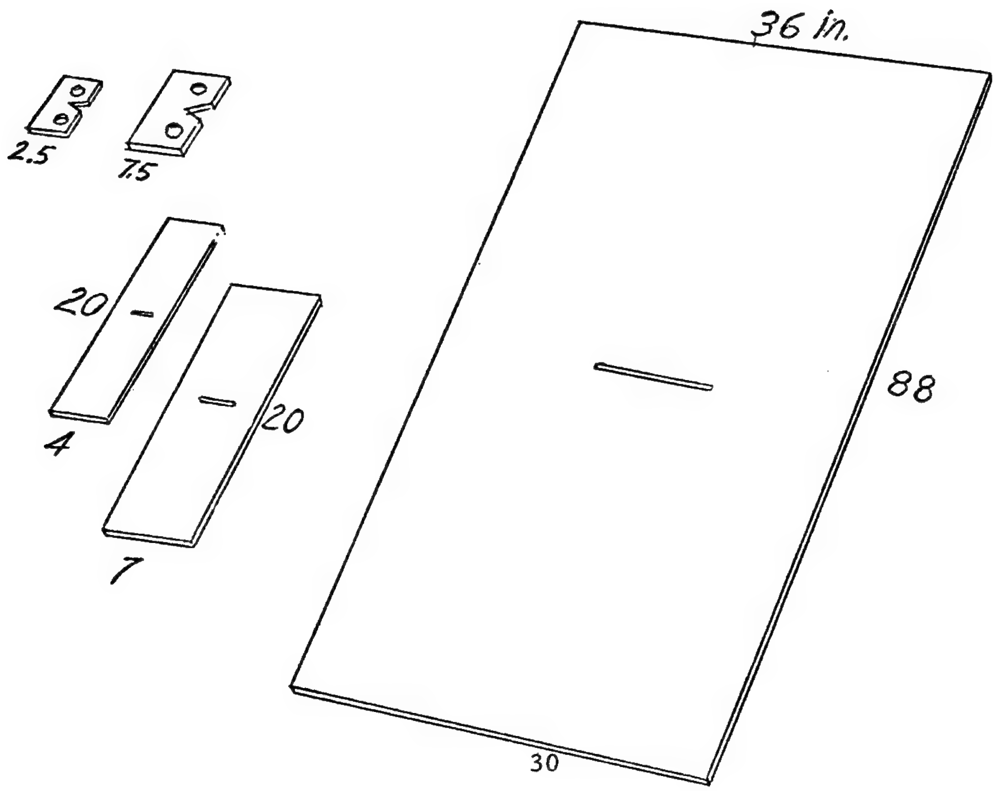


FRACTURE OF B/AL LAMINATES

Correlation of Failing Strains and Fracture Equations



GRAPHITE/EPOXY FRACTURE SPECIMENS



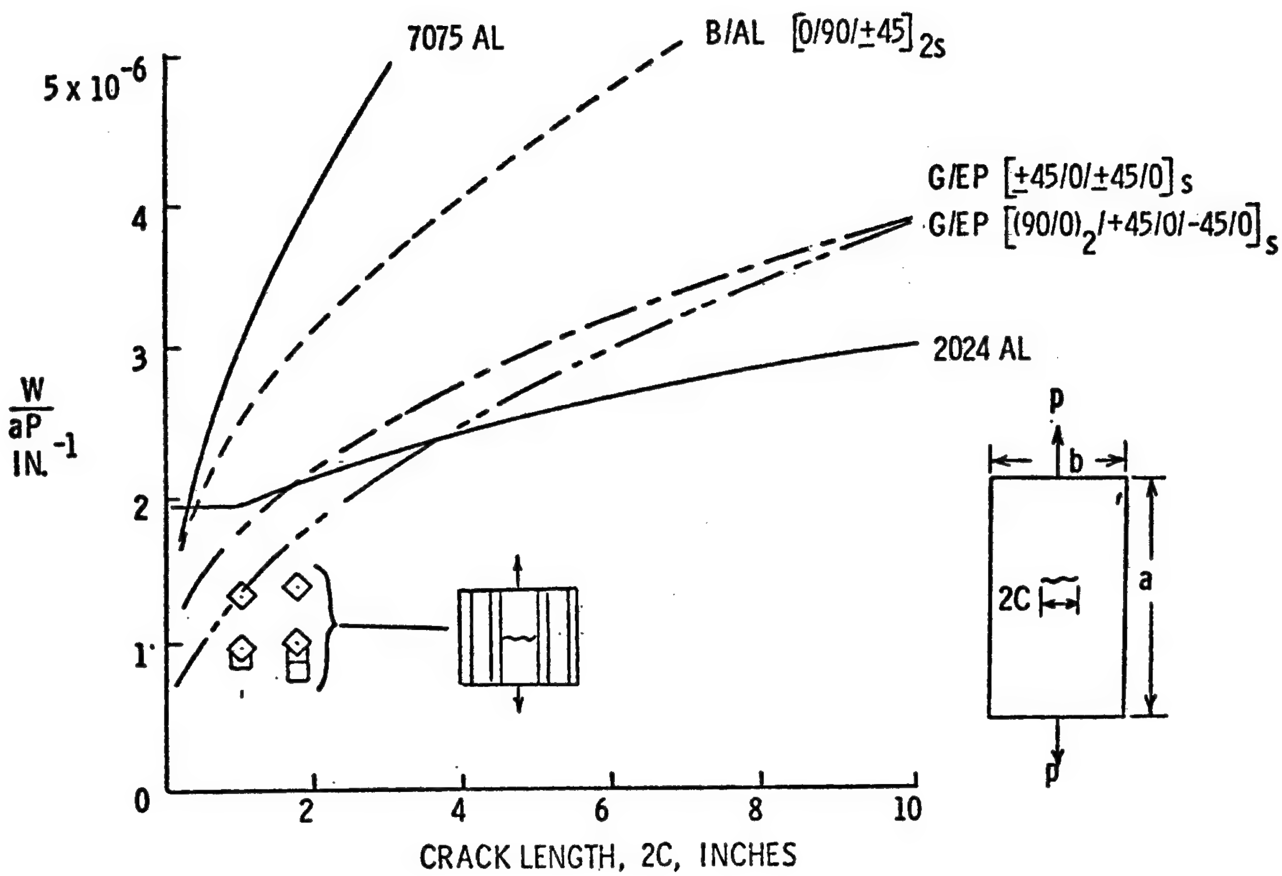
OTHER BASIC FRACTURE WORK IN PROGRESS

INVESTIGATION OF B/AL LAMINATES WITH HOLES

INVESTIGATION OF Gr/Ep LAMINATES WITH CRACKS AND HOLES

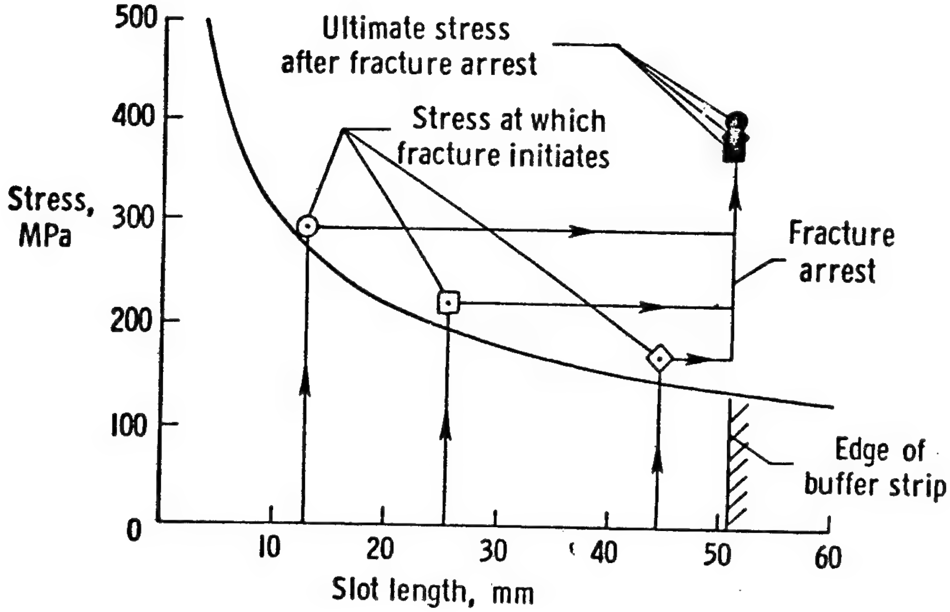
FRACTURE ANALYSES USING DISCRETE FIBER-MATRIX MODELS

WEIGHT INDEX FOR TENSION PANELS



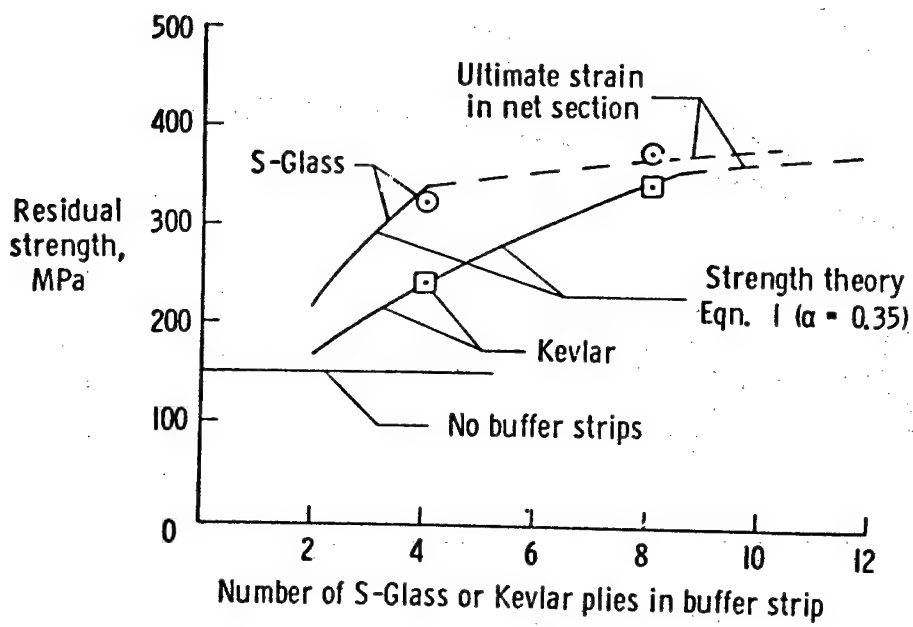
DAMAGE TOLERANT PANELS

Load History of $[45/0/-45/90]_{2S}$ Gr/Ep Panels with 8-ply, S-Glass Buffer Strips



DAMAGE TOLERANT PANELS

Strength Analysis for $[45/0/-45/90]_{2S}$ Gr/Ep Buffer Strip Panels with Arrested Cracks 50.8-mm Long



OTHER DAMAGE TOLERANT WORK IN PROGRESS

TESTS OF PANELS WITH

$[45/0/-45/0]_{2s}$ LAMINATES

MYLAR INTERPOSED BUFFER STRIPS

BONDED STRINGERS

ANALYSES OF PANELS

DISCRETE FIBER-MATRIX MODELS

WITH BONDED STRINGERS

WITH BUFFER STRIPS

ADVANCED-COMPOSITE COMPRESSION STRUCTURES

- o STIFFENED-PANEL DESIGN TECHNOLOGY
- o EFFECT OF LOW-VELOCITY IMPACT DAMAGE ON COMPRESSIVE STRENGTH
- o RING-STIFFENED CORRUGATED CYLINDER

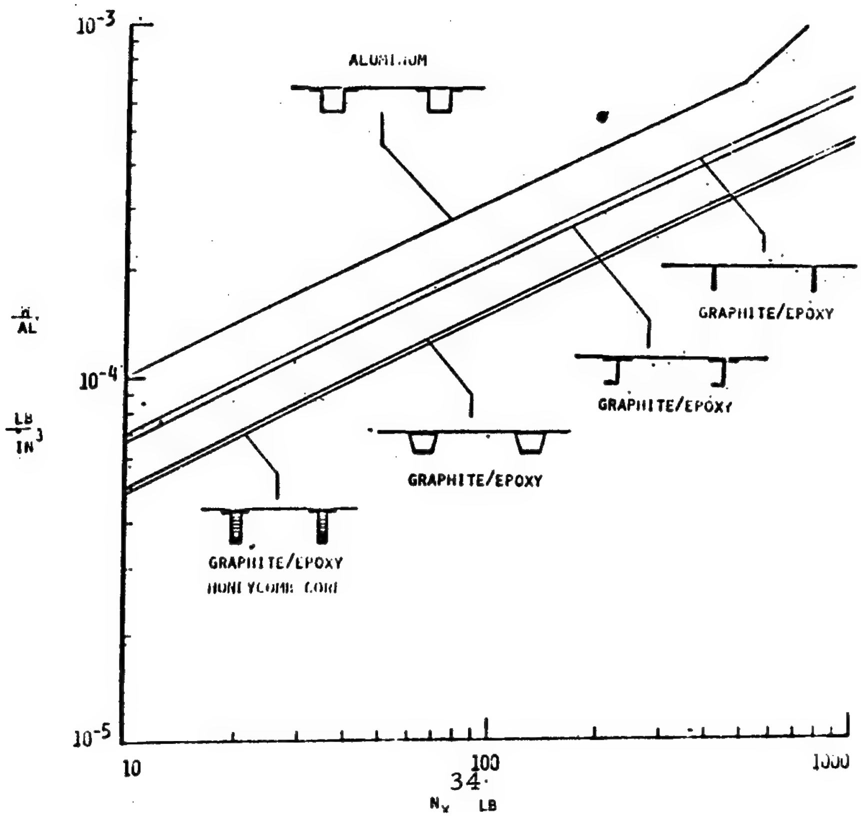
JAMES H. STARNES, JR.

STRUCTURAL MECHANICS BRANCH

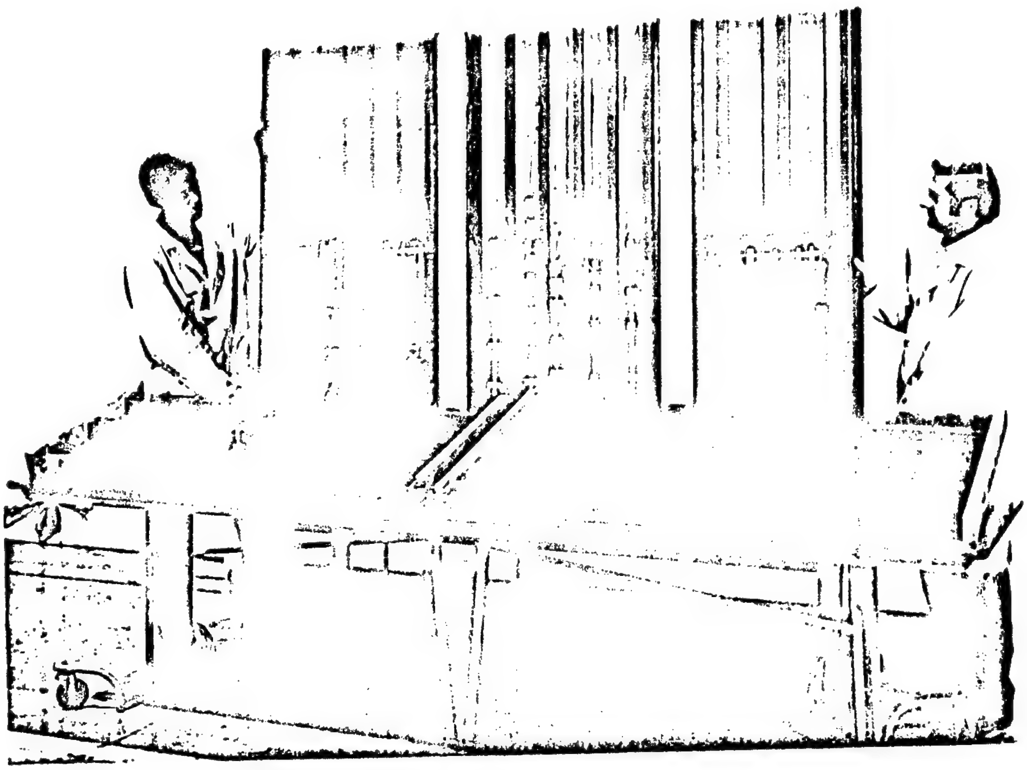
LANGLEY RESEARCH CENTER

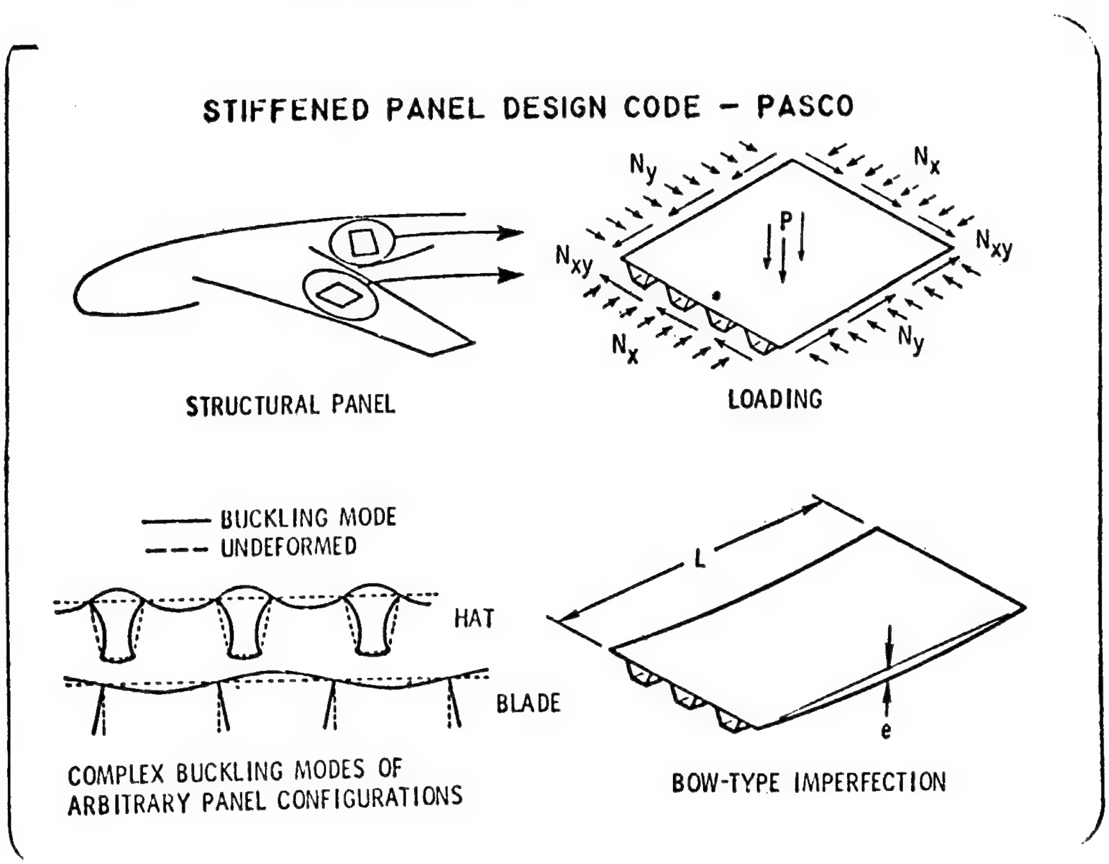
NO ________

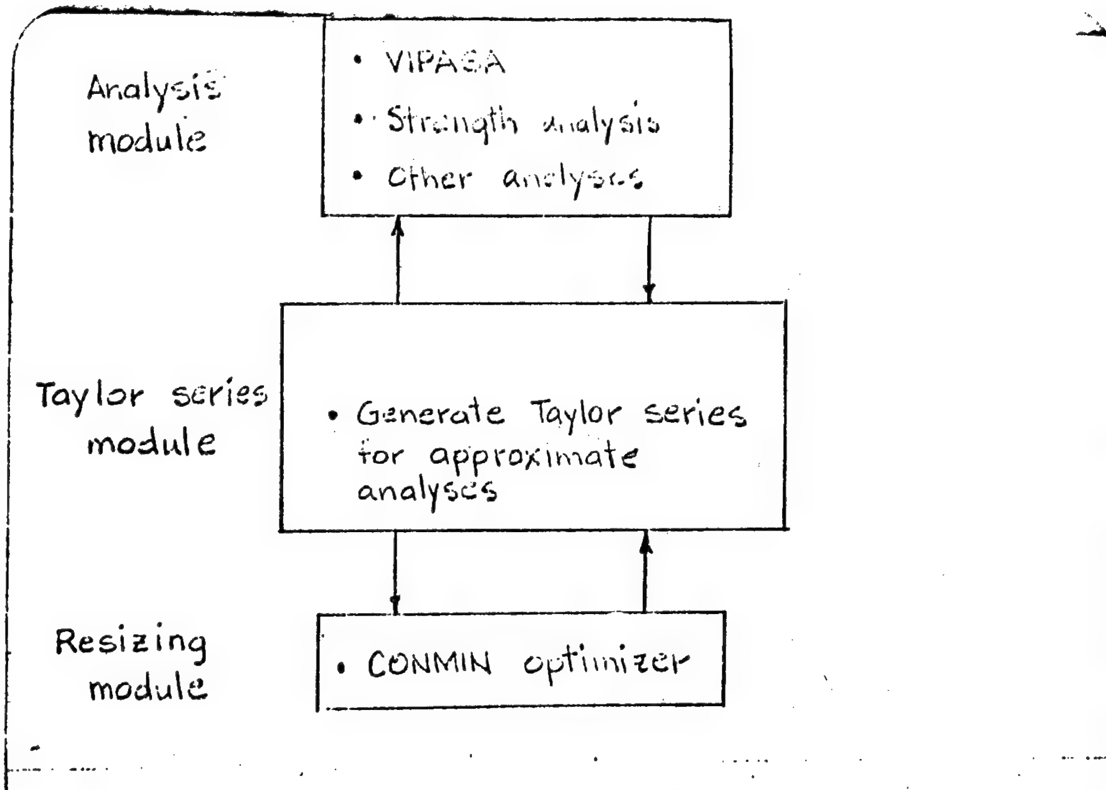
STRUCTURAL EFFICIENCY OF SEVERAL STIFFENER CONFIGURATIONS



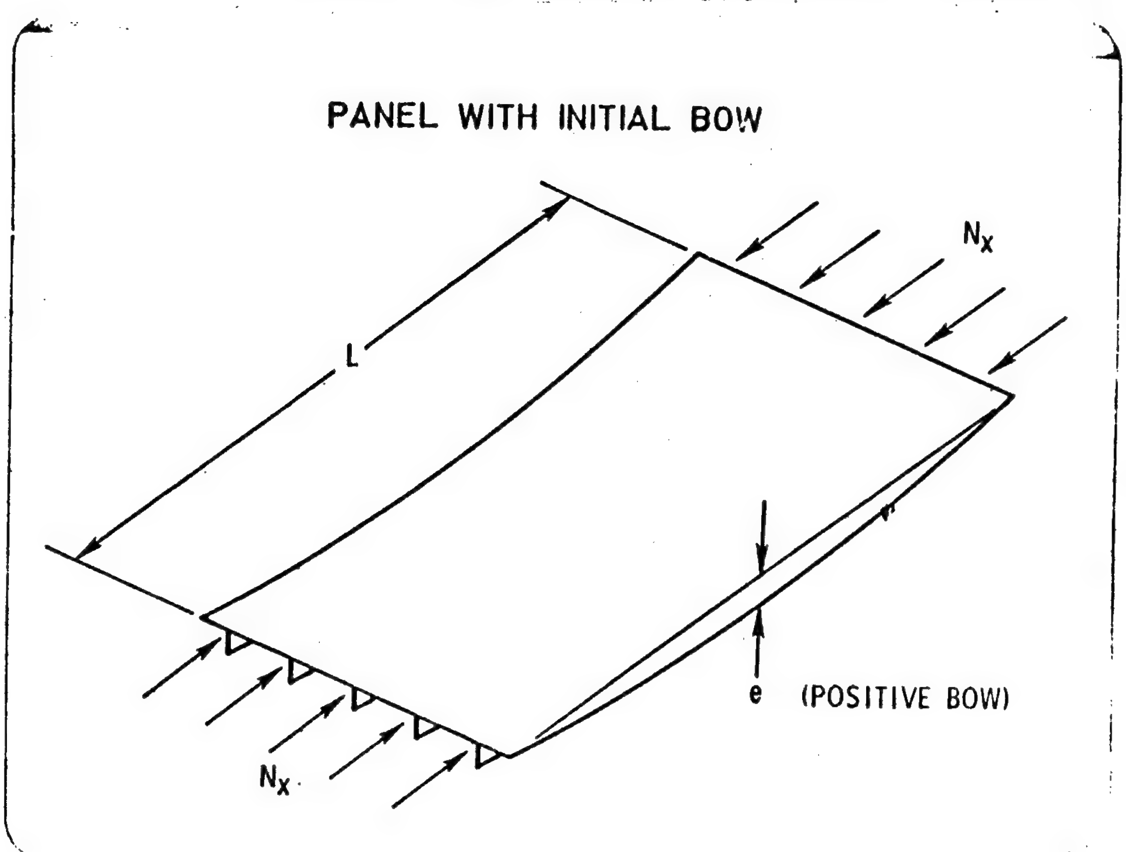
NASA
L 77-7717





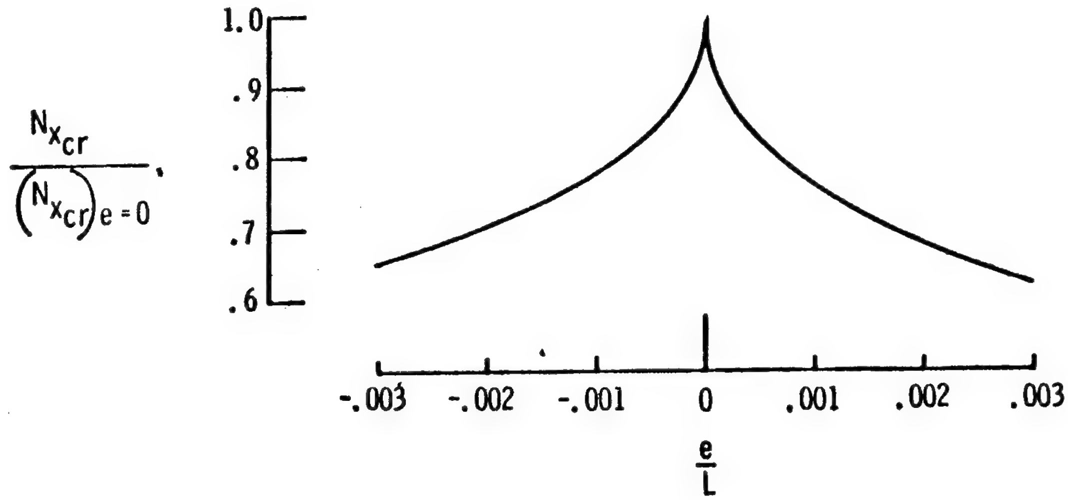


General approach used in present procedure

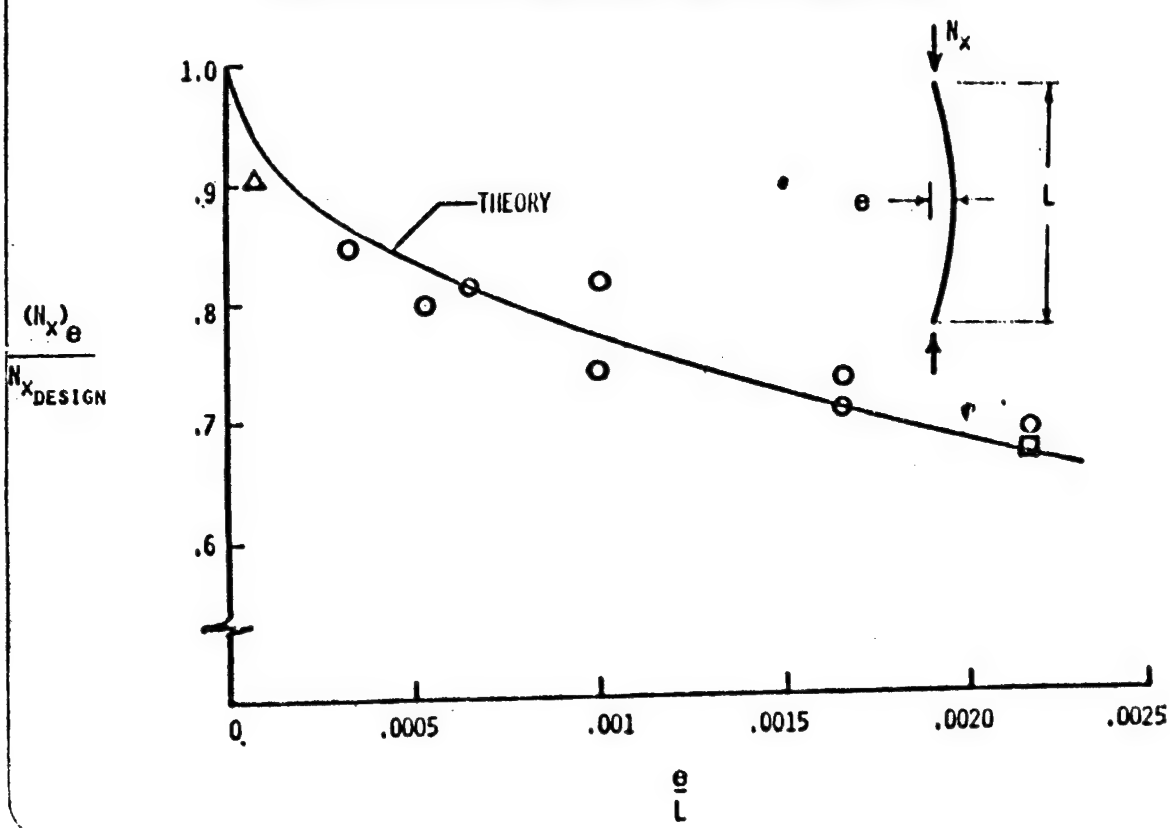


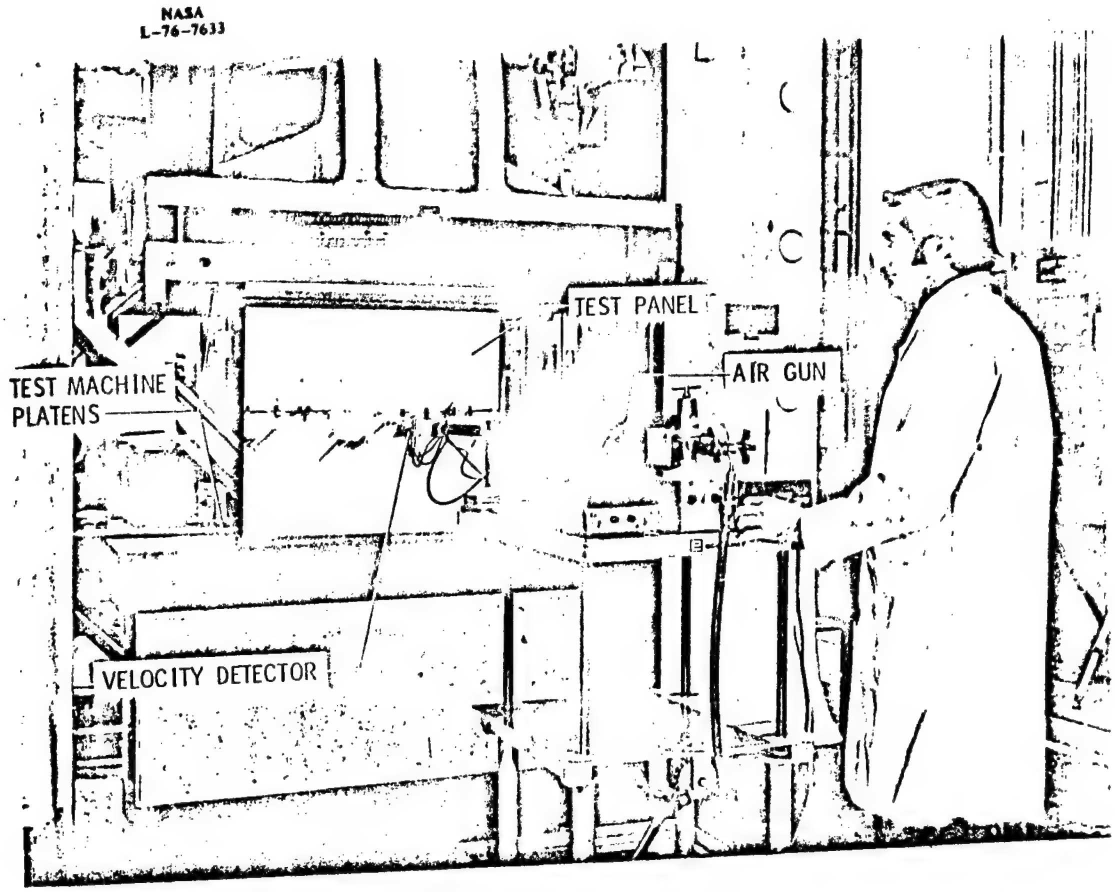
EFFECT OF BOW ON BUCKLING LOAD

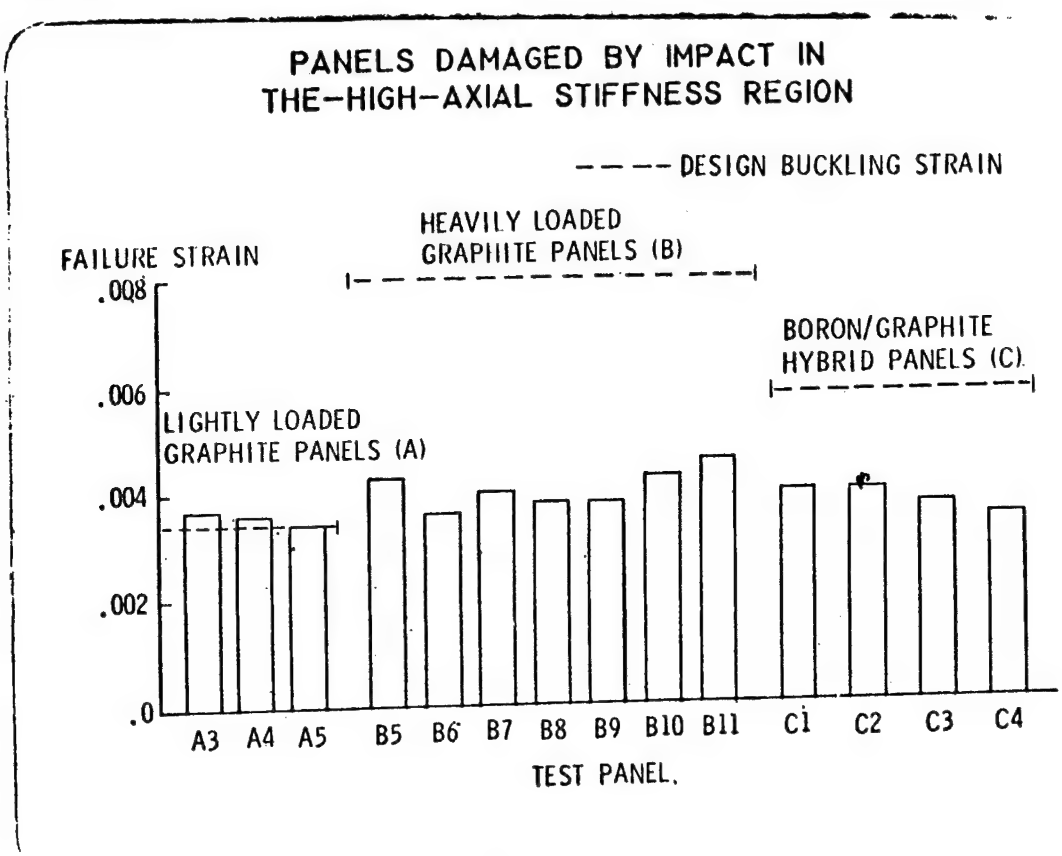
BLADE - STIFFENED PANEL



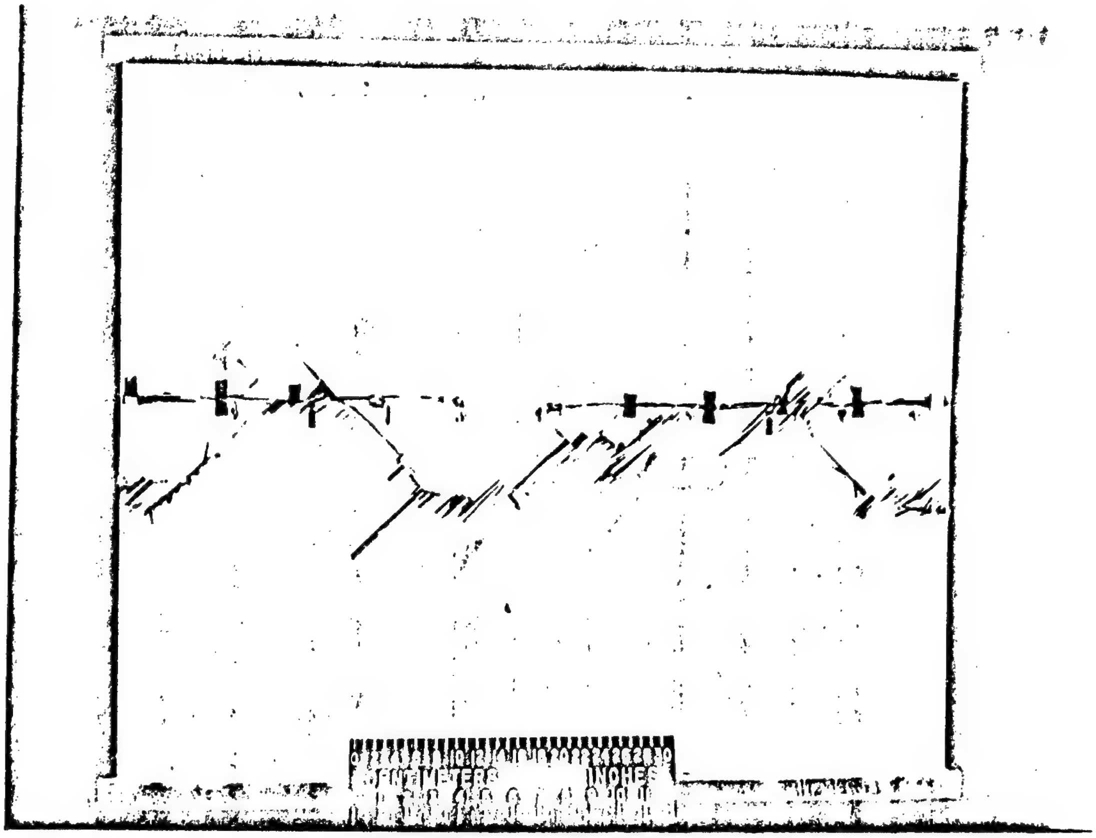
SENSITIVITY OF GR/E COMPRESSION PANELS TO IMPERFECTIONS



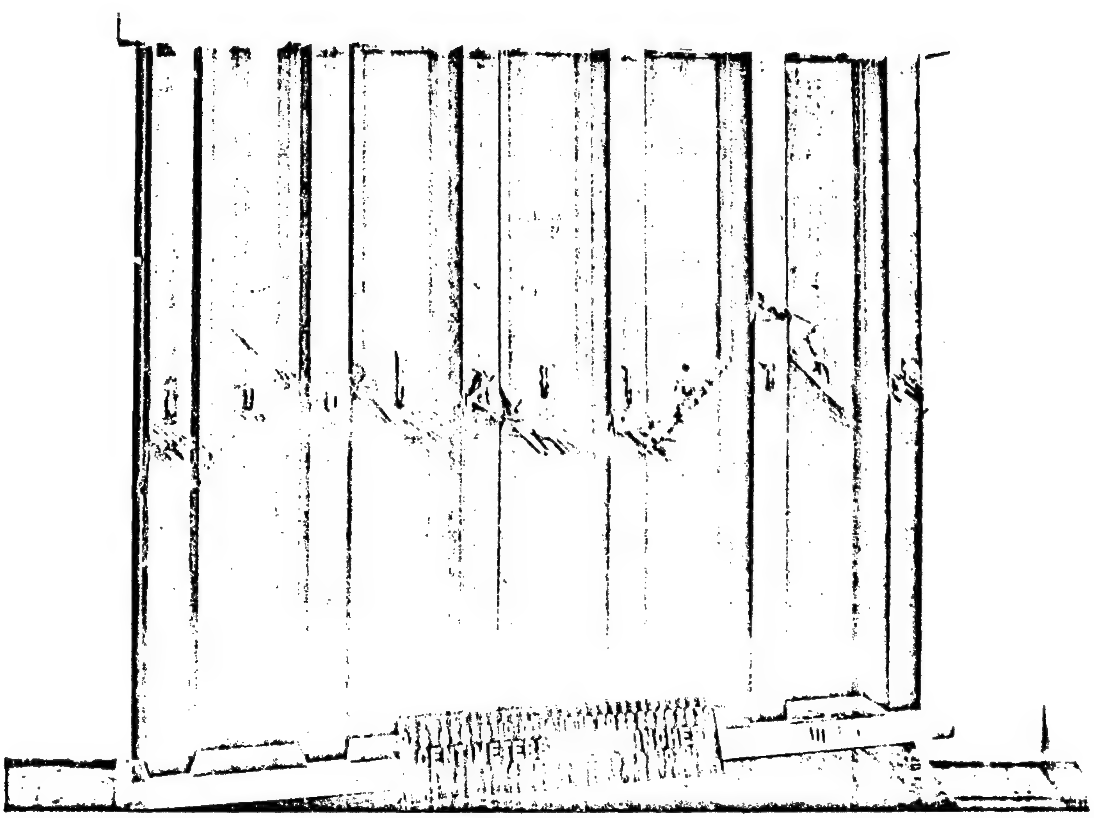

NASA
L-76-7633
TEST PANEL
AIR GUN
TEST MACHINE
PLATENS
VELOCITY DETECTOR

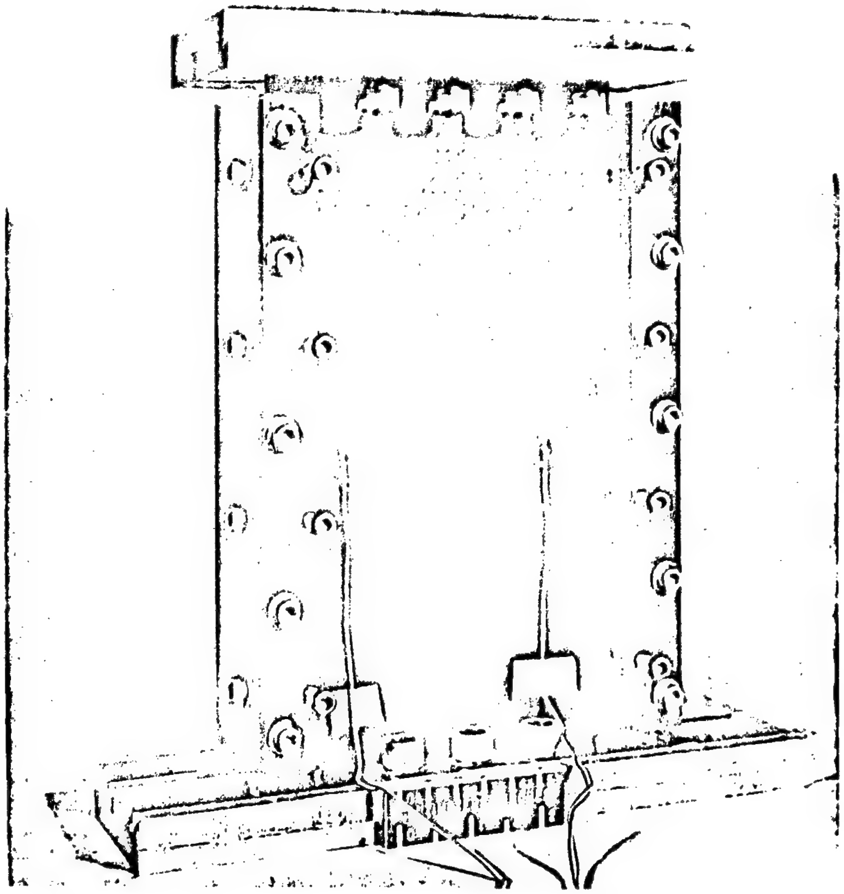

PANELS DAMAGED BY IMPACT IN
THE-HIGH-AXIAL STIFFNESS REGION
---- DESIGN BUCKLING STRAIN
HEAVILY LOADED
GRAPHITE PANELS (B)
FAILURE STRAIN
BORON/GRAPHITE
HYBRID PANELS (C)
LIGHTLY LOADED
GRAPHITE PANELS (A)
.008
.006
.004
.002
.0
A3 A4 A5 B5 B6 B7 B8 B9 B10 B11 C1 C2 C3 C4
TEST PANEL

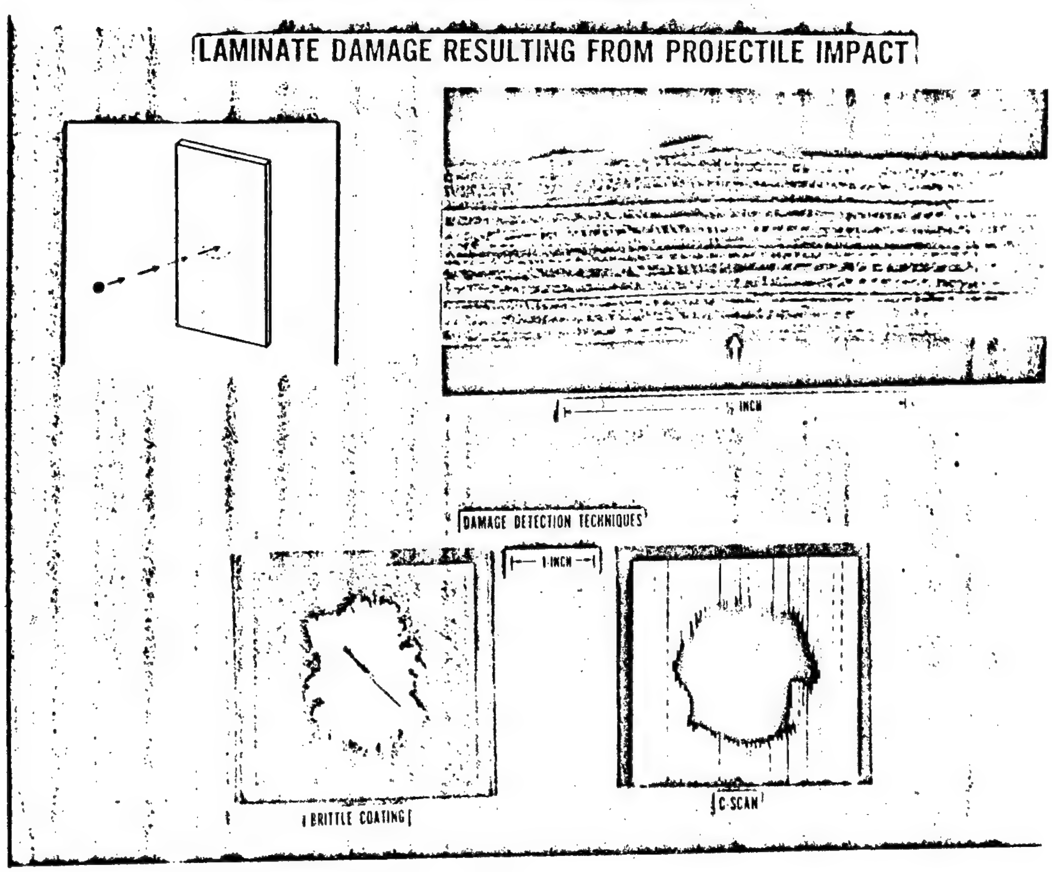
NASA
L 76 7632



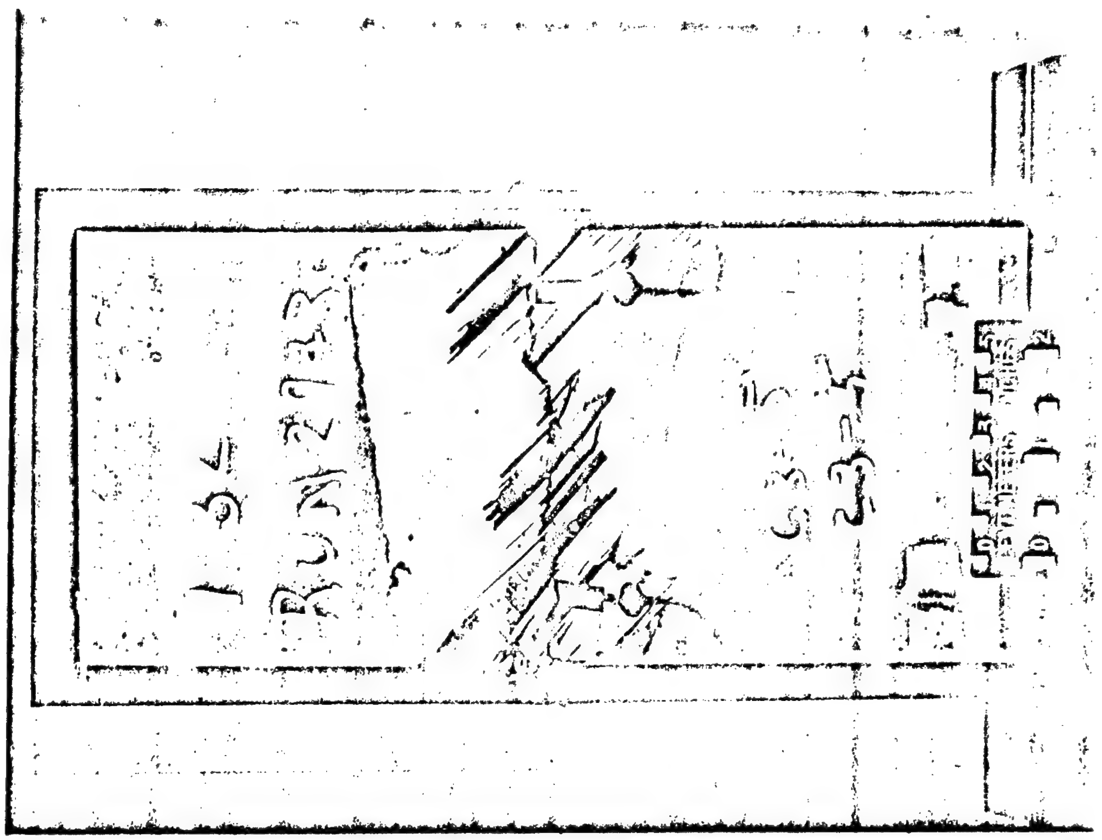
NASA
L-76-7634



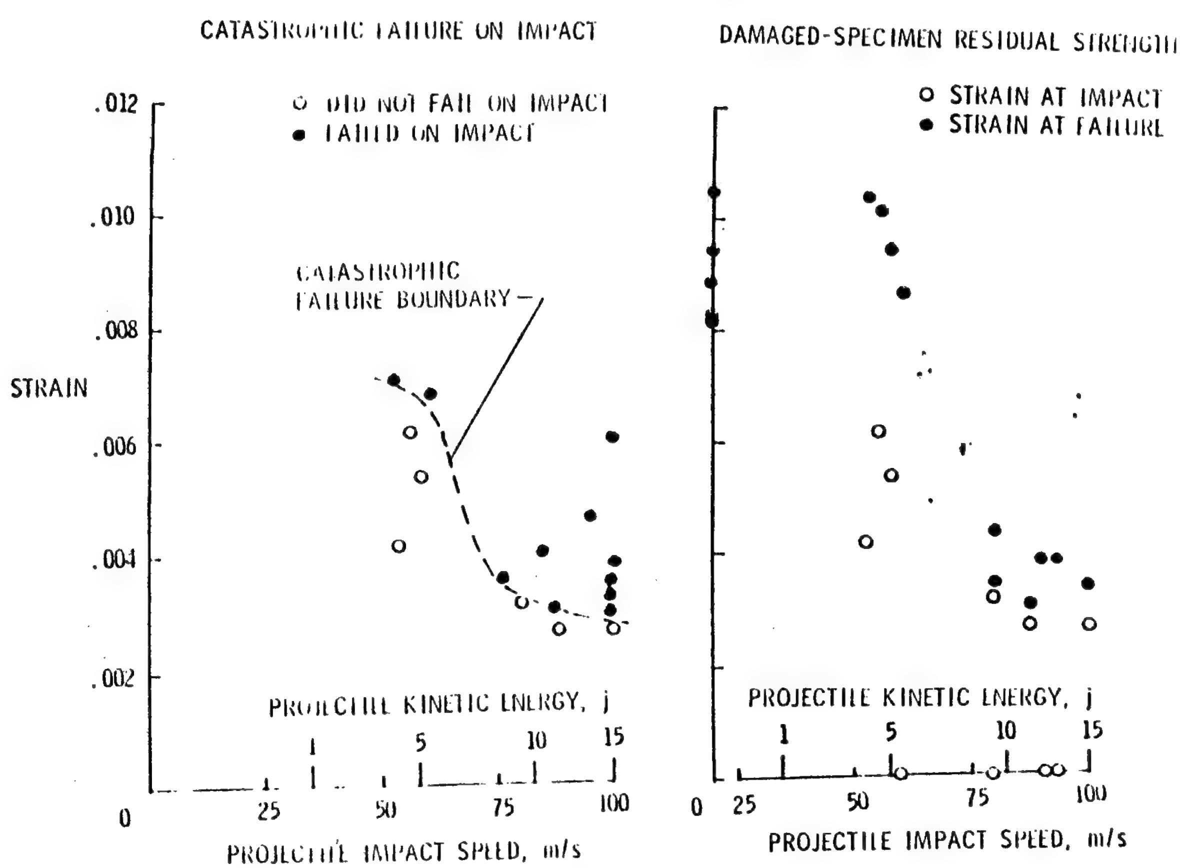



LAMINATE DAMAGE RESULTING FROM PROJECTILE IMPACT
½ INCH
DAMAGE DETECTION TECHNIQUES
1-INCH
BRITTLE COATING
C-SCAN

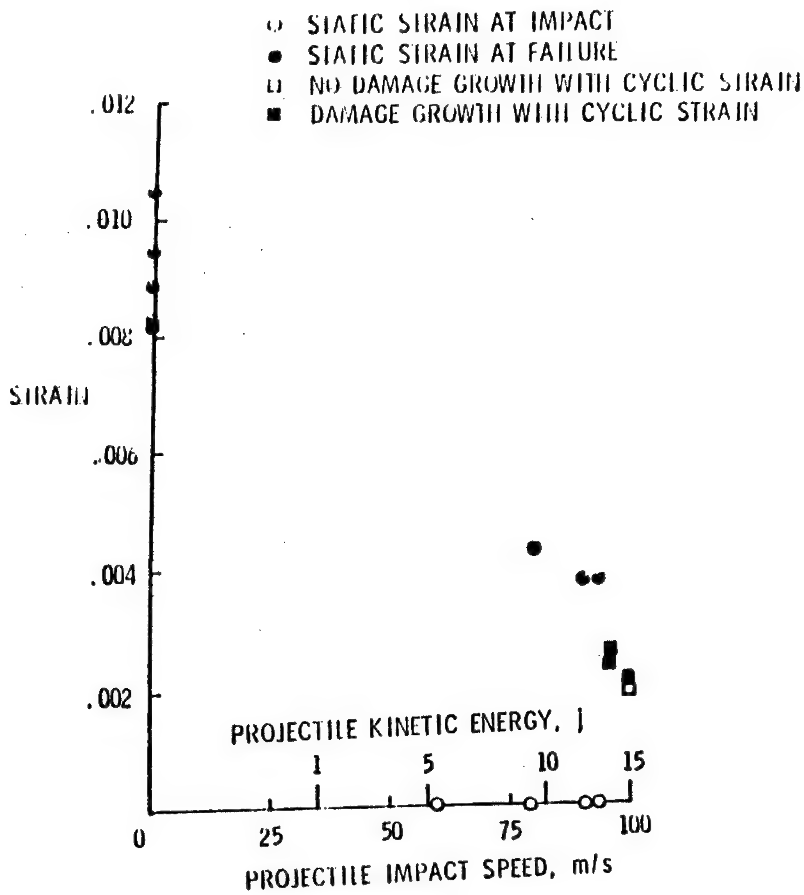
NASA
L-77-4440



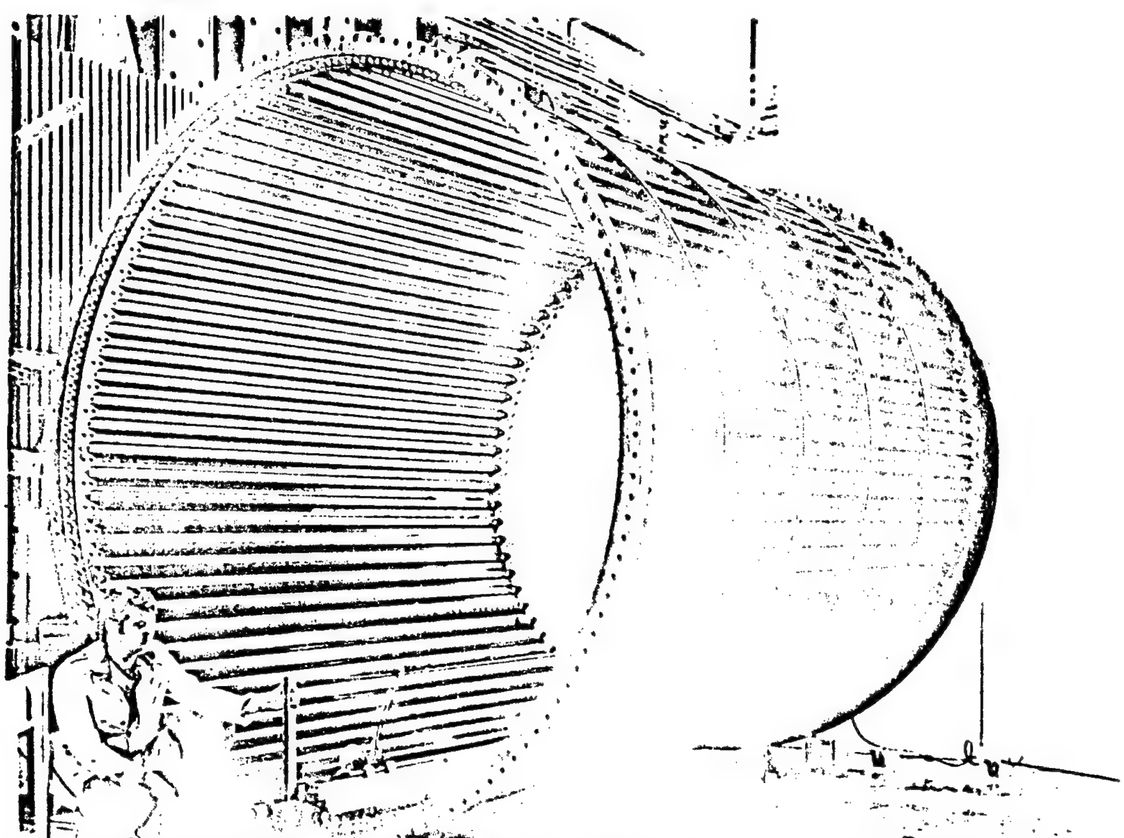
EFFECT OF IMPACT-DAMAGE ON STATIC COMPRESSION STRENGTH

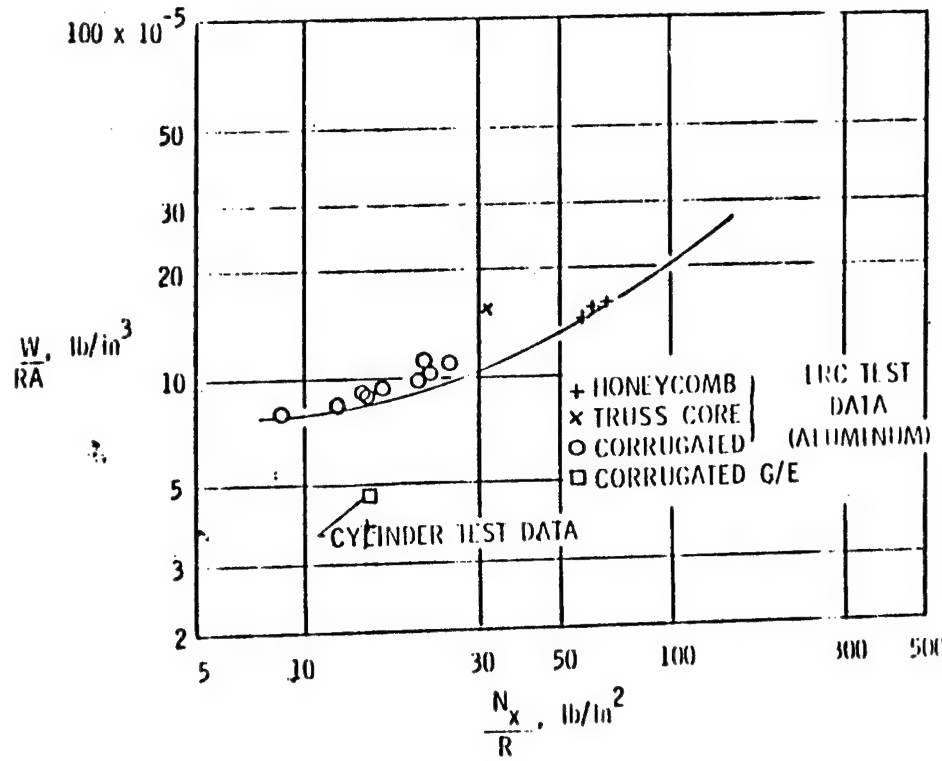


EFFECT OF IMPACT DAMAGE ON CYCLIC COMPRESSION STRENGTH



NASA
L-78-1271




100 x 10^-5
50
30
20
10
5
3
2
W/RA, lb/in^3
5
10
30
50
100
300
500
Nx/R, lb/in^2
+ HONEYCOMB
x TRUSS CORE
O CORRUGATED
LRC TEST DATA (ALUMINUM)
□ CORRUGATED G/E
CYLINDER TEST DATA

AIR FORCE MATERIALS LABORATORY

NONMETALLIC COMPOSITES/MECHANICS

MECHANICS OF COMPOSITES/FAILURE MECHANISMS

OBJECTIVE: IDENTIFY THE PHYSICS OF FAILURE IN LAMINATED COMPOSITES UNDER BOTH STATIC AND FATIGUE LOADING.

APPROACH: PHYSICAL OBSERVATION OF FAILURE PROCESSES UNDER HIGHLY CONTROLLED CONDITIONS.

TRANSITION: FORMS THE BASIS FOR DEVELOPING A MINER'S RULE FOR COMPOSITES.

6T NONMETALLIC COMPOSITES/ MECHANICS MECHANICS OF COMPOSITES/ FAILURE MECHANISMS	GOAL: TO IDENTIFY CRITICAL FAILURE MODES FROM WHICH PERFORMANCE CAN BE MONITORED AND PREDICTED.						
	FY78	FY79	FY80	FY81	FY82	FY83	TOTAL
LIFE PREDICTION							
LIFE PREDICTION, I/H (6.2) (WUD 45)	1.0	1.5	1.8	1.8	1.8		
IMPROVED COMPOSITES (6.2) UDRI							
DEFECT/PROP (6.2)							
STATISTICAL FAILURES (6.2)					3A		
FAILURE OF LAMINATES (6.2)							
CUMULATIVE DAMAGE (6.2)							

NONMETALLIC COMPOSITES/MECHANICS

MECHANICS OF COMPOSITES/DURABILITY

OBJECTIVE: DEVELOP ANALYTICAL AND EXPERIMENTAL METHODOLOGY FOR PREDICTING THE COMBINED EFFECTS OF MOISTURE/TEMPERATURE/STRESS ON THE MECHANICAL BEHAVIOR OF LAMINATED COMPOSITES.

APPROACH: ANALYTICAL MODELS BASED ON EXPERIMENTAL OBSERVATION OF PHYSICAL BEHAVIOR.

TRANSITION: PROVIDES BASIS FOR ASSESSING DURABILITY OF COMPOSITES FOR MATERIALS DEVELOPMENT OR FOR DESIGN (3A, AFFDL, INDUSTRY).

6T NONMETALLIC COMPOSITES/ MECHANICS MECHANICS OF COMPOSITES/ DURABILITY		GOAL: TO INSURE PERFORMANCE OF COMPOSITES UNDER ANTICIPATED LOADS AND ENVIRONMENT THROUGHOUT ENTIRE LIFE.						
		FY78	FY79	FY80	FY81	FY82	FY83	TOTAL
GURANTEED PERFORMANCE								
DURABILITY I/H (WUD 45)	(6.2)	1.8	2.0	2.0	2.0	2.0		
IMPROVED COMPOSITES UDRI	(6.2)							
MOISTURE EFFECTS	(6.2)							
TIME-DEP BEHAVIOR	(6.2)							
COMPR LOADING	(6.2)							
LOAD HISTORY	(6.2)							
ENVIRON IMPACTS	(6.2)							

NONMETALLIC COMPOSITES/MECHANICS

MECHANICS OF COMPOSITES/MATERIALS IMPROVEMENTS

OBJECTIVE: TO ESTABLISH RATIONAL BASIS TO SELECT CONSTITUENT MATERIALS, INTERFACE TREATMENT AND CURE CYCLE FOR IMPROVED PERFORMANCE.

APPROACH: TO USE ADVANCED THEORIES OF INELASTIC AND FAILURE MECHANICS TO MODEL MICROMECHANICS AND CURE CYCLE FROM WHICH FIGURES OF MERITS CAN BE IDENTIFIED AND QUANTITATIVELY DEFINED.

TRANSITION: PROVIDE KEY INFORMATION TO 7T, 6T (MATERIALS), 3A AND INDUSTRY.

6T NONMETALLIC COMPOSITES/ MECHANICS MECHANICS OF COMPOSITES/ MATERIALS IMPROVEMENTS	GOAL: TO ESTABLISH RATIONAL CRITERIA FOR SELECTION AND PROCESSING OF CONSTITUENTS AND LAMINATE MATERIALS.					
	FY78	FY79	FY80	FY81	FY82	FY83	TOTAL
OPTIMUM MATERIALS							
MATERIALS IMPROVE, I/H (6.2)	0.6	1.0	1.2	1.2	1.2		
NOVEL DESIGN (6.1)							
(6.2)							
OPTIMIZED CURING (6.2)							
HYBRID COMP (6.2)							
METAL MATRIX COMP (6.2)							
MAINTENANCE FREE COMP (6.2)							

DURABILITY/LIFE PREDICTION OF COMPOSITES AND ADHESIVE JOINTS

TASK I MECHANICS OF COMPOSITES

LIFE PREDICTION: ANALYTICAL MODELING BASED ON PROBABLISTIC THEORIES SHALL BE USED TO DEVELOP A SYSTEMATIC TEST MATRIX FROM WHICH LIFE PREDICTION METHODOLOGY SHALL BE DEVELOPED. IN THE EXPERIMENTAL PHASE, THE INTERACTION BETWEEN A LOADING HISTORY AND REALISTIC ENVIRONMENTS SHALL BE CRITICALLY ASSESSED. LONG TERM DURABILITY OF COMPOSITES CAN THEN BE EVALUATED WITH SPECIFIED LEVELS OF RELIABILITY.

FAILURE MECHANISMS: THIS SHALL BE APPROACHED ON TWO LEVELS; THE COMPOSITE AS A WHOLE AND THE INTERFACIAL LEVEL. THE APPROACH WILL INVOLVE USING SEVERAL NDI TECHNIQUES TO DETECT AND MONITOR THE DEVELOPMENT OF DAMAGE ZONES IN THE COMPOSITE AS A FUNCTION OF LOADING AND COMPOSITE PARAMETERS, AND THE USE OF FRACTOGRAPHY TO STUDY FRACTURE SURFACES. THE ROLE OF THE FIBER SURFACE, AND FIBER/MATRIX INTERPHASE ON COMPOSITE DURABILITY AND MECHANICAL PROPERTIES WILL BE STUDIED THROUGH THE USE OF SURFACE ENERGETICS, SURFACE COMPOSITION AND MICROSCOPIC TECHNIQUES ON SINGLE FILAMENT SPECIMENS. INTERFACIAL PROPERTIES AND DURABILITY WILL BE DETERMINED BY MECHANICAL TESTING.

DEFECT - PROPERTY RELATIONSHIPS IN COMPOSITE MATERIALS

INVESTIGATORS

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OBJECTIVES:

1. TO IDENTIFY THE PRECISE NATURE OF DAMAGE DEVELOPMENT IN QUASI-ISOTROPIC GRAPHITE-EPOXY LAMINATES UNDER VARIOUS LOAD HISTORIES.

2. TO DETERMINE THE PHYSICAL PARAMETERS WHICH LEAD TO A LOSS OF STRENGTH AND/OR LIFE.

3. TO ESTABLISH THE MECHANICS OF THE INDIVIDUAL AND COMBINED ACTION OF THESE PARAMETERS AS THEY INFLUENCE MECHANICAL RESPONSE.

4. TO ADDRESS THE QUESTION OF HOW THESE FINDINGS CAN BEST BE DESCRIBED BY ANALYSIS.

INVESTIGATIVE PROGRAM:

MATERIAL: AS/3501 GRAPHITE EPOXY

SPECIMENS: TYPE I - $(0,\pm45,90)_s$,

TYPE II - $(0,90,\pm45)_s$,

TYPE III - $(0,90_2,\pm45)_s$,

TYPE IV - $(90_2,0,\pm45)_s$

METHODS

- INSTRUMENTED TENSILE TESTS
- FATIGUE TESTS
- SEM AND LIGHT MICROSCOPE STUDIES
- REPLICATION STUDIES
- ACOUSTIC EMISSION AND ULTRASONIC ATTENUATION STUDIES
- VIDEO AND THERMOGRAPHIC STUDIES
- SECTIONING STUDIES
- LAMINATE THEORY CALCULATIONS - FAILURE PREDICTIONS
- EQUILIBRIUM ELEMENT AND FINITE DIFFERENCE ANALYSES OF DAMAGE STATE

GENERAL

- LOAD HISTORY STUDIES
- TRANSVERSE CRACK AND DELAMINATION INVESTIGATION - INITIATION, GROWTH, AND FRACTURE
- TECHNIQUE DEVELOPMENT - ULTRASONIC ATTENUATION, THERMOGRAPHY, REPLICATION
- ANALYSIS EVALUATION AND DEVELOPMENT

EARLIER FINDINGS

QUASI-STATIC LOADING

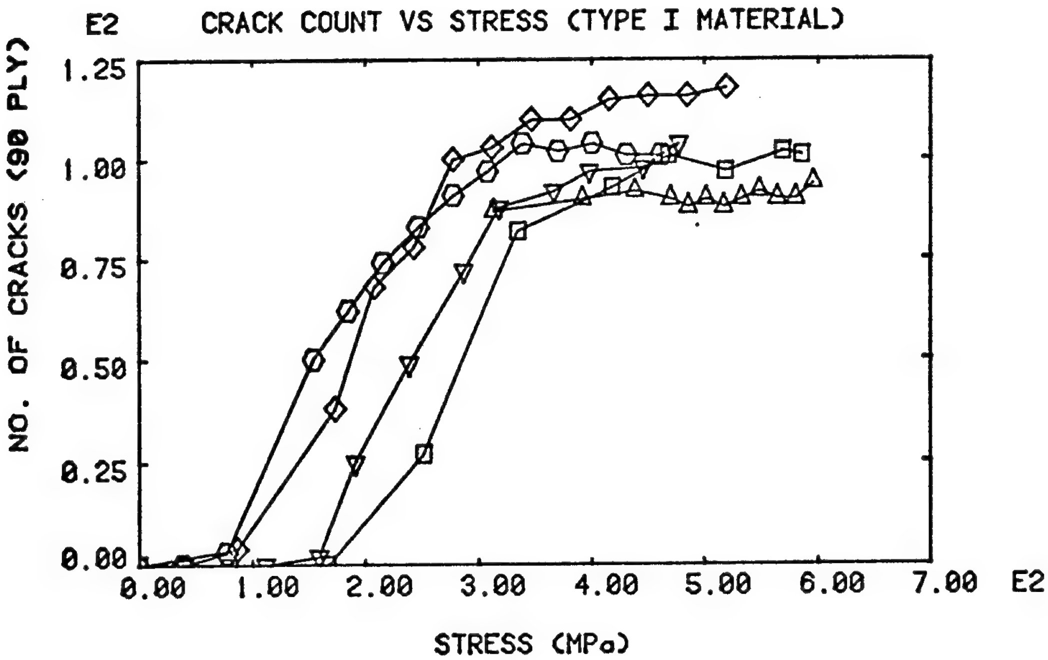
1. CRACKS APPEAR AT LEVELS OF LOAD AS LOW AS 1/3 OF ULTIMATE FRACTURE LOAD, CORRESPONDING TO THE LEVEL PREDICTED IF THERMAL RESIDUAL STRESSES ARE INCLUDED.
2. THE GRADUAL DEVELOPMENT OF CRACKS IN THE WEAKEST PLY (FIRST PLY FAILURE) OCCURS OVER A RANGE OF STRESS BOUNDED ABOVE BY A STRESS LEVEL WHICH APPROXIMATELY CORRESPONDS TO THE "KNEE" IN THE LOAD-EXTENSION CURVE.
3. CRACKS DO PROPAGATE FROM ONE LAYER TO ANOTHER, AND ACROSS THE WIDTH OF PLATE SPECIMENS.
4. THE DIFFERENCE IN THE STRESS STATE AT THE EDGE AND INTERIOR OF THE LAMINATES IS REFLECTED IN DISTINCTIVE DAMAGE FEATURES SUCH AS EDGE DELAMINATION, ANGULAR CRACKING OF 45° PLIES AT THE EDGE, AND SOMEWHAT HIGHER CRACK DENSITIES IN THE INTERIOR IN SOME CASES.
5. INTERLAMINAR STRESSES DO INFLUENCE DAMAGE INITIATION, GROWTH AND INTERACTION, AS EVIDENCED BY A DEPENDENCE OF FAILURE STRENGTH AND DAMAGE MODES ON STACKING SEQUENCE.
6. THE STRENGTH OF THE $[0°,90°,\pm45°]_s$ LAMINATES IS SOMEWHAT GREATER THAN THE $[0°,\pm45°,90°]_s$ LAMINATES.

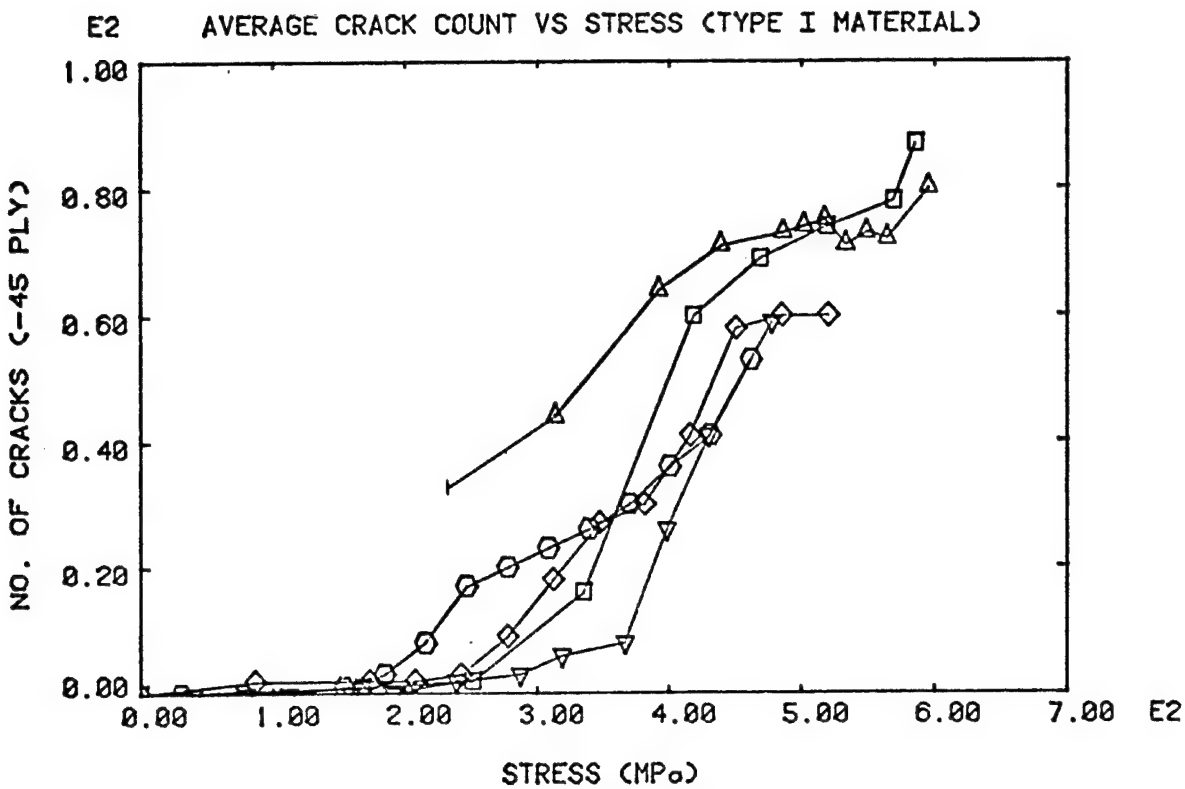
CYCLIC LOADING

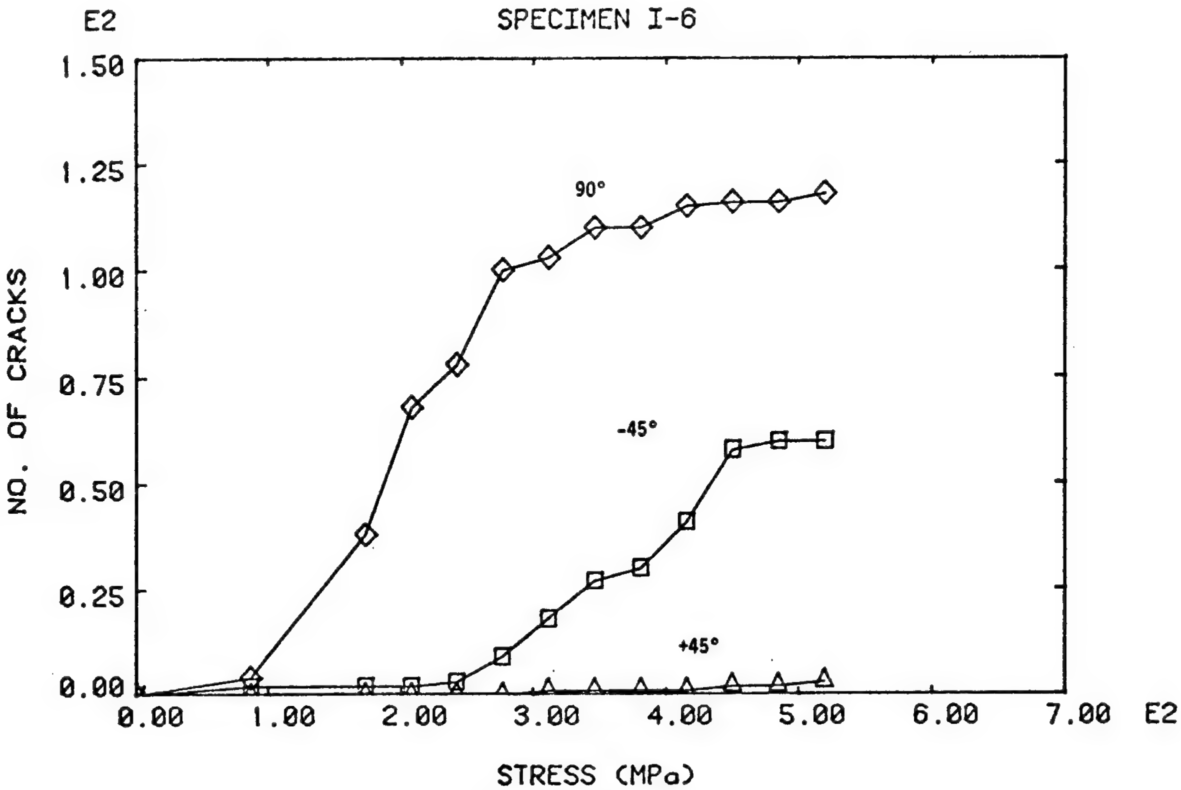
7. DAMAGE IN THESE LAMINATES CONSISTS OF THE DEVELOPMENT OF EQUILIBRIUM SPACINGS OF CRACKS IN EACH PLY BY MEANS OF CRACK INITIATION AND GROWTH OVER A SIGNIFICANT LOAD RANGE OR NUMBER OF CYCLES OF LOAD APPLICATION. THESE EQUILIBRIUM SPACINGS CAN BE PREDICTED BY ANALYSIS.
8. INITIAL CRACKS DO NOT APPEAR TO BE OF ANY SPECIAL CONSEQUENCE.
9. CYCLED LOADING INCREASES THE DENSITY OF CRACKS IN A GIVEN PLY COMPARED TO A SINGLE APPLICATION OF LOAD TO THE SAME LEVEL. THE MODE OF FAILURE UNDER CYCLIC LOADING IS NOT IDENTICAL TO STATIC FAILURE MODES UNDER OTHERWISE IDENTICAL CONDITIONS.

NONDESTRUCTIVE INVESTIGATION

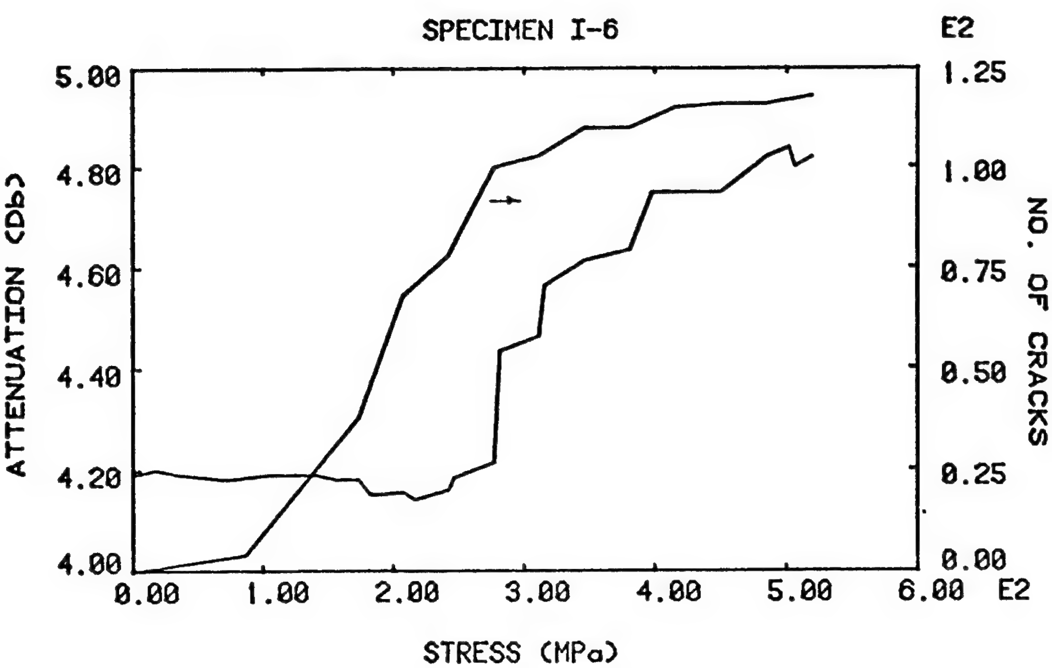
10. NONDESTRUCTIVE TEST METHODS SUCH AS STIFFNESS DETERMINATION, VIDEO-THERMOGRAPHY AND MEASUREMENT OF ULTRASONIC ATTENUATION ARE VERY USEFUL TECHNIQUES FOR THE DETECTION AND INVESTIGATION OF DAMAGE DEVELOPMENT.
11. CRACK FORMATION AND GROWTH IN THE INTERIOR OF A SPECIMEN CAN BE DETECTED BY NDT; ULTRASONIC METHODS APPEAR TO BE BEST SUITED FOR THE PURPOSE.


E2
CRACK COUNT VS STRESS (TYPE I MATERIAL)
NO. OF CRACKS (90 PLY)
1.25
1.00
0.75
0.50
0.25
0.00
0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 E2
STRESS (MPa)

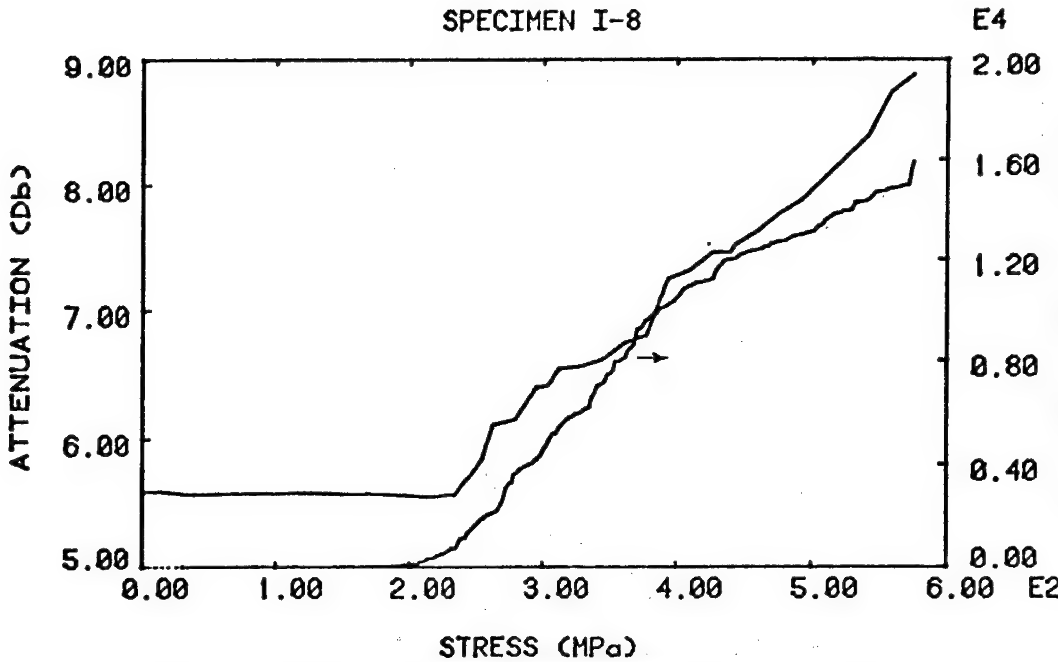

E2
AVERAGE CRACK COUNT VS STRESS (TYPE I MATERIAL)
NO. OF CRACKS (-45 PLY)
1.00
0.80
0.60
0.40
0.20
0.00
0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 E2
STRESS (MPa)



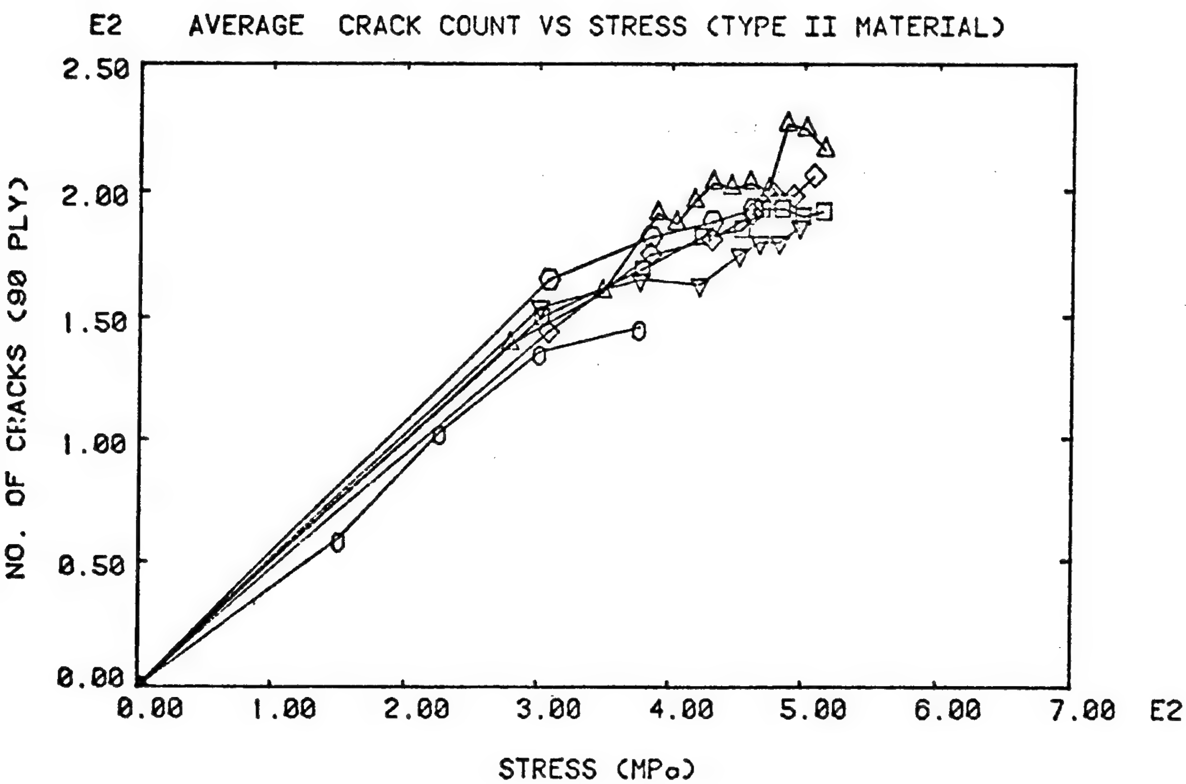
Number of cracks on the edge of a type I specimen vs. applied tensile stress.

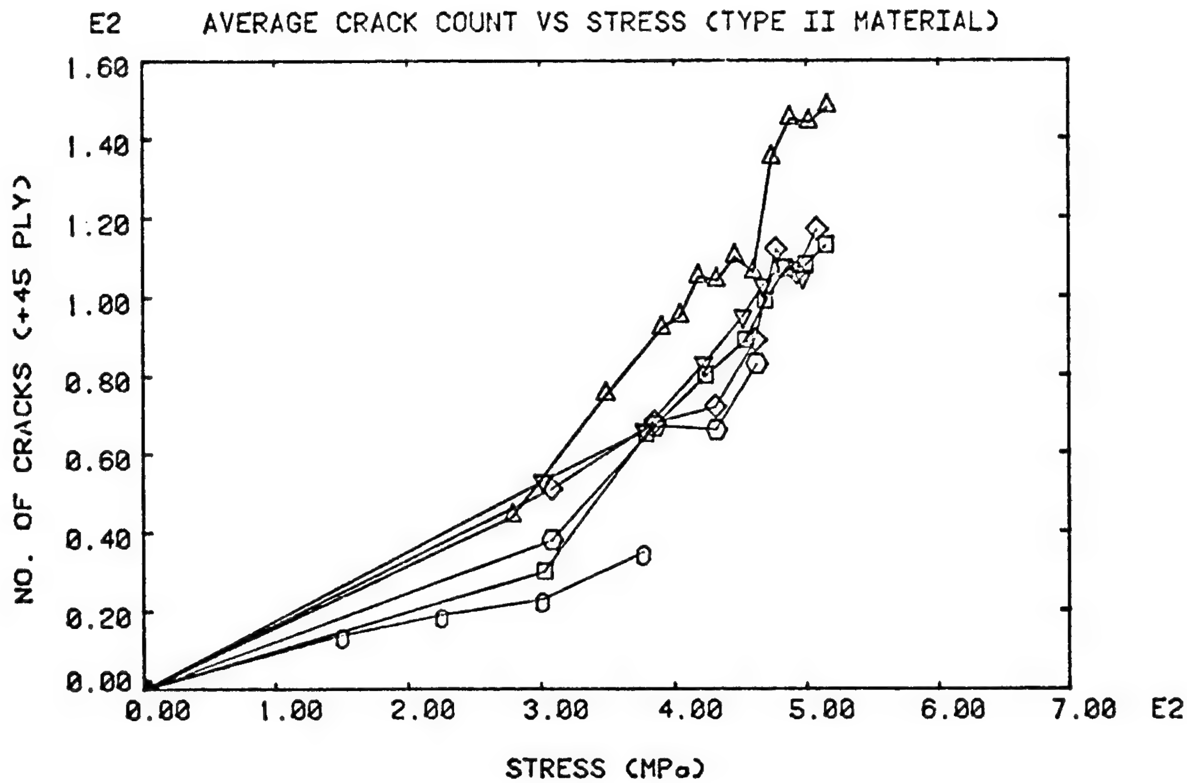


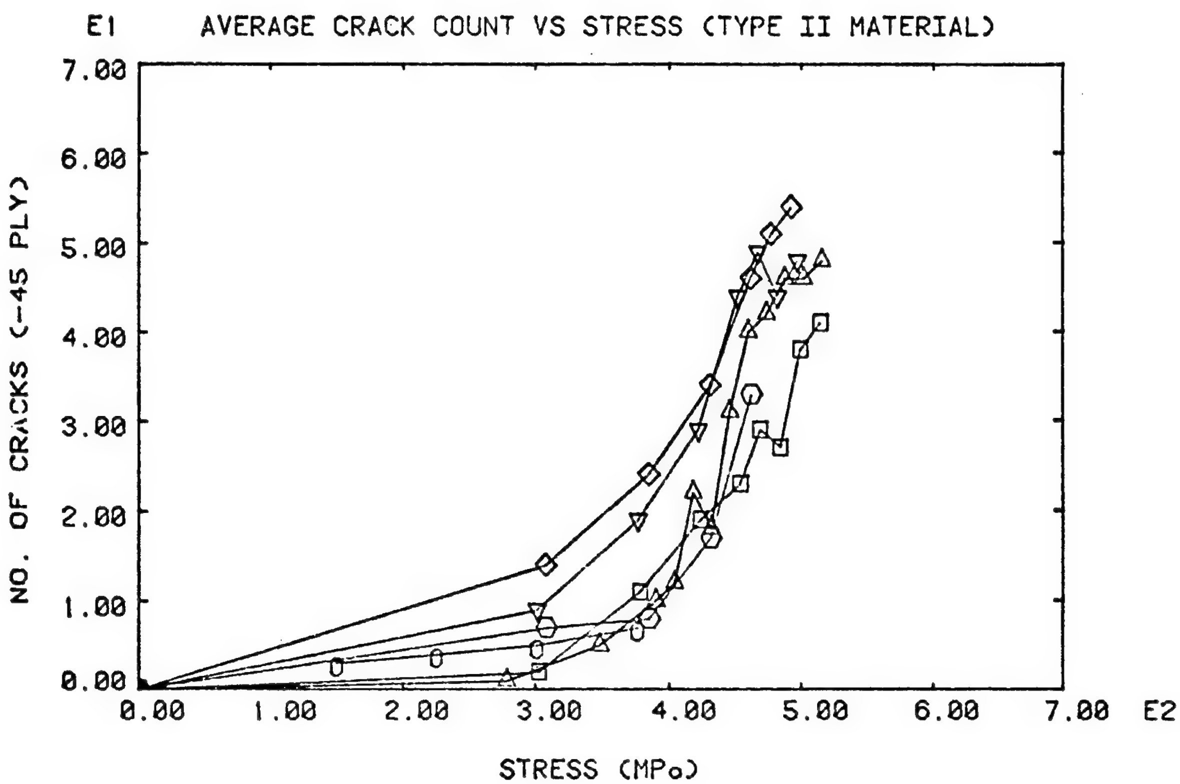
Attenuation change and number of cracks in 90° ply vs. applied tensile stress on a type I specimen.

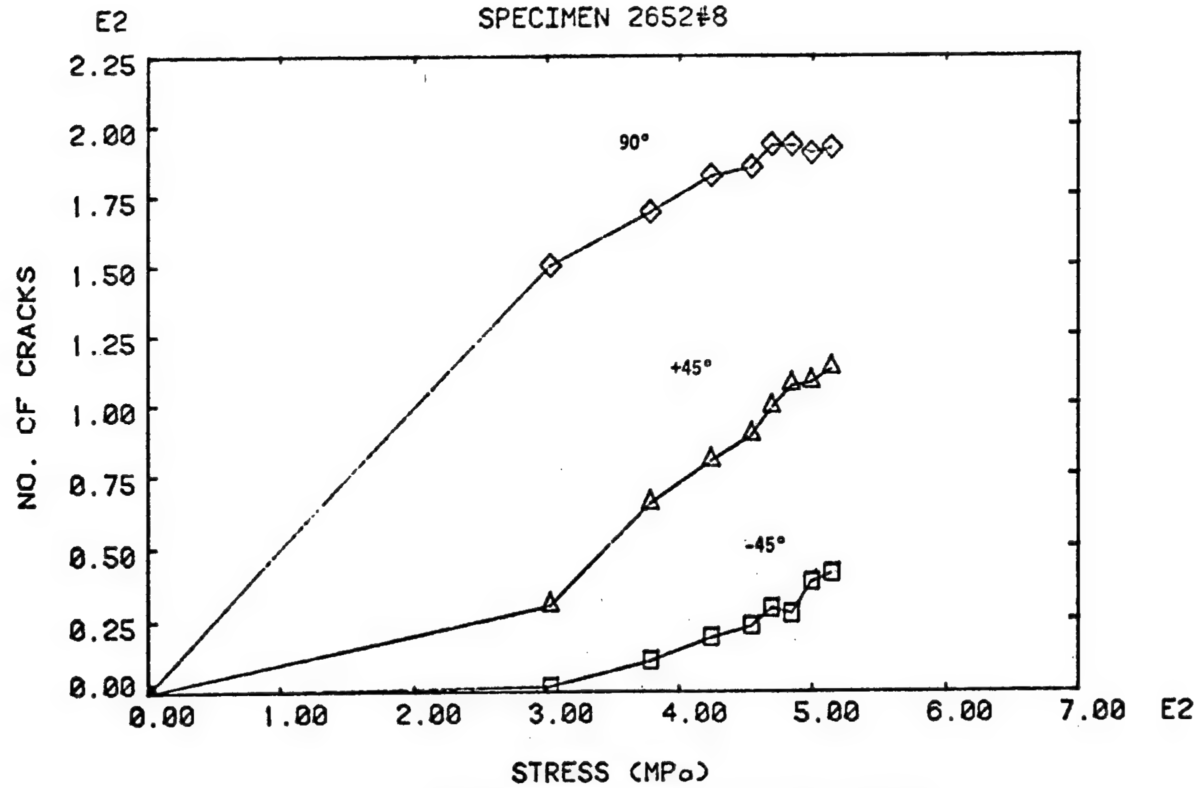


Attenuation change and total acoustic emission counts vs. applied tensile stress on a type I specimen.

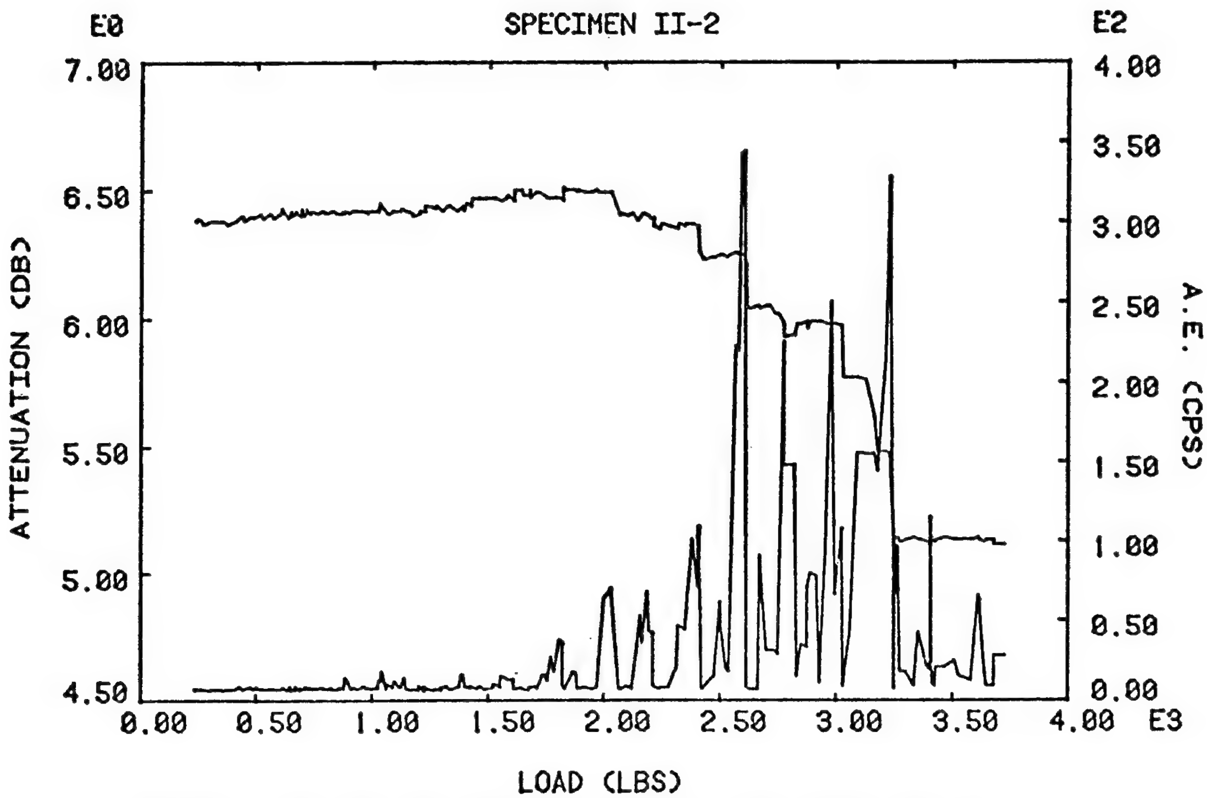



E2
AVERAGE CRACK COUNT VS STRESS (TYPE II MATERIAL)
NO. OF CRACKS (+45 PLY)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
E2
STRESS (MPa)


E1
AVERAGE CRACK COUNT VS STRESS (TYPE II MATERIAL)
NO. OF CRACKS (-45 PLY)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
E2
STRESS (MPa)



Number of cracks on the edge of a type II specimen vs. applied tensile stress.

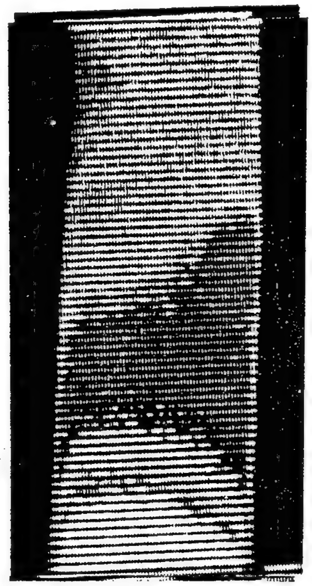


Attenuation change and acoustic emission count rate vs. applied tensile load on a type II specimen.

a) Static b) 50 Cycles c) 10 000 Cycles

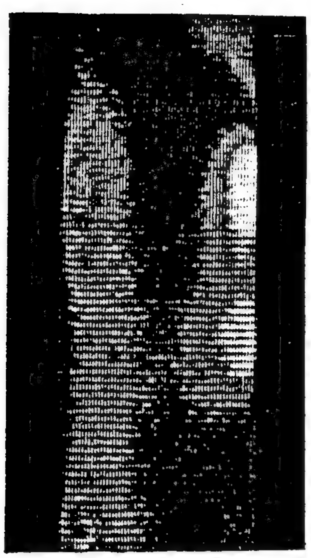
Edge damage history in a Type I specimen a σ_{max} = 42 ksi.

a) 34 ksi, N=10^4 cyc

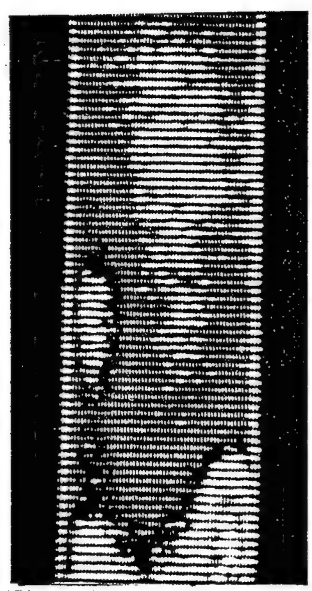


b) 42 ksi, N=1 cyc

c) 42 ksi, N=10^4 cyc

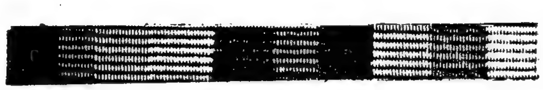


d) 57 ksi, N=1 cyc



e) 57 ksi, N=500 cyc

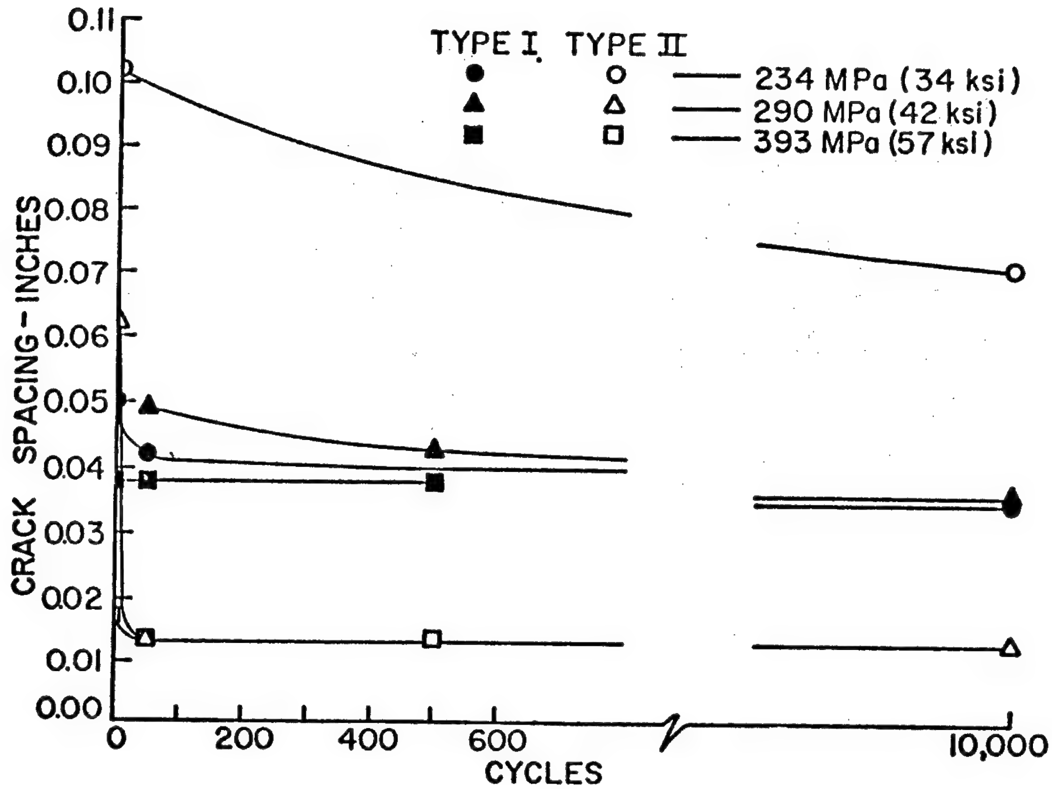
f) 57 ksi, N=500 cyc



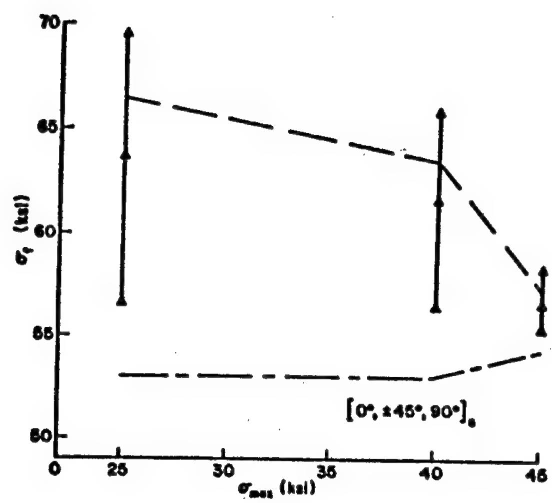
Vibrothermographs of Type I specimens.

a) Static b) 50 Cycles c) 10 000 Cycles

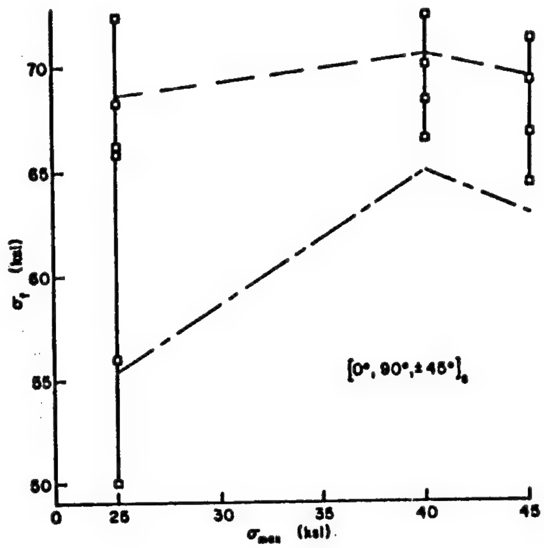
Edge damage history in a Type II specimen at σ_{max} = 42 ksi.



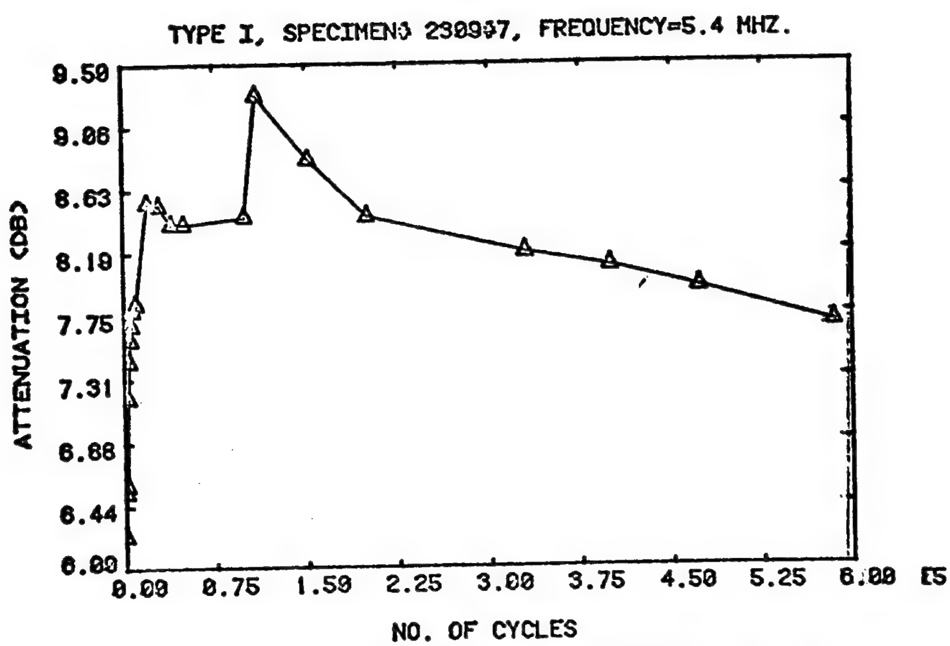
Spacing of transverse cracks in the 90° plies of Type I and Type II specimens for several load histories.



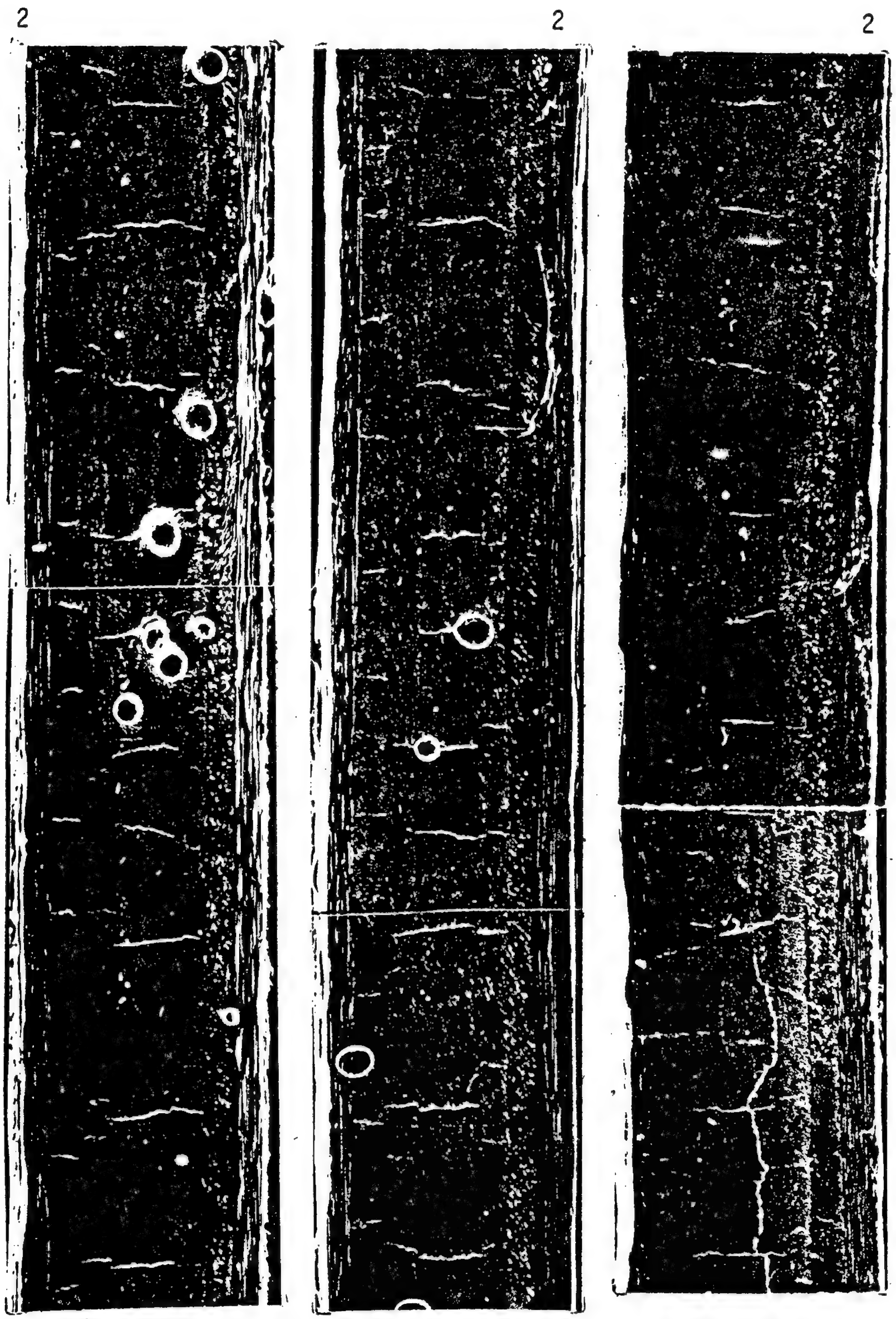
Residual strength of type I specimens after one million cycles at the indicated stress levels



Residual strength of type II specimens after one million cycles at the indicated stress levels

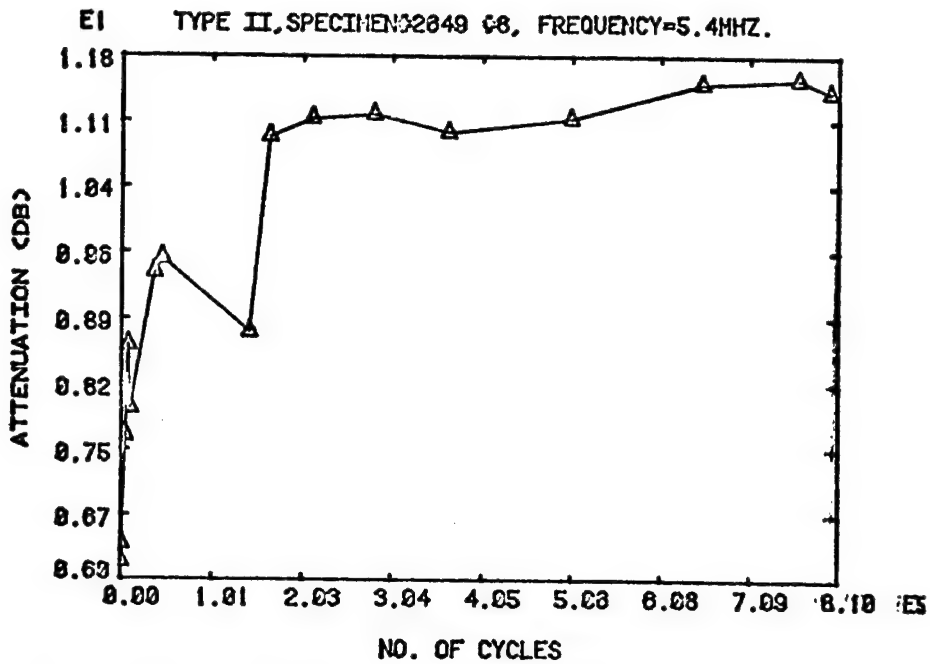


No. of cycles vs. attenuation for cyclic-tension-tension test for type I specimen (2309#7 at 40 ksi).

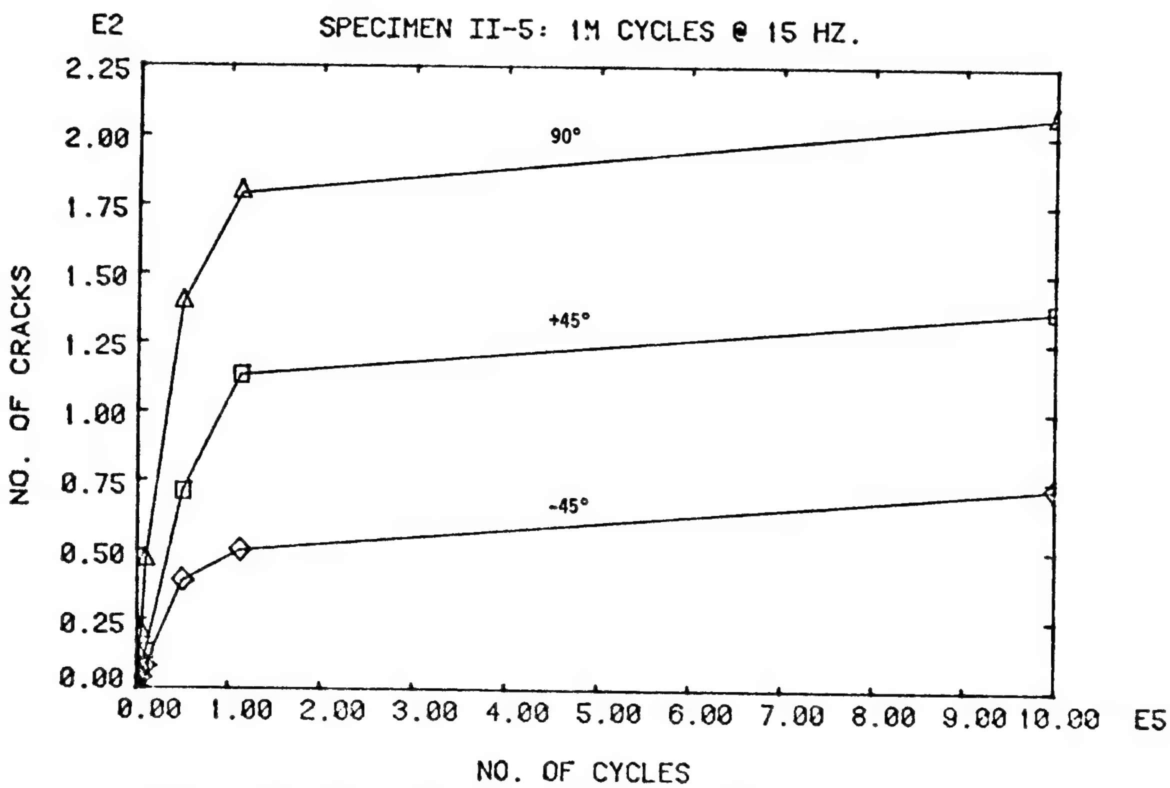


a) 0.372"　　b) 0.325"　　c) 0.186"

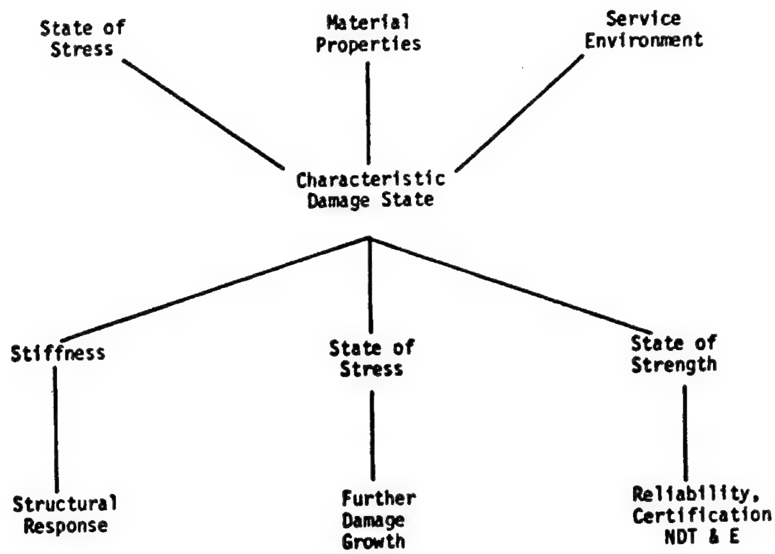
Damage in the interior of the specimen (2309#7, 40 ksi, 1M cycles) at x = 0.372, 0.325 and 0.186" from the outer edge.

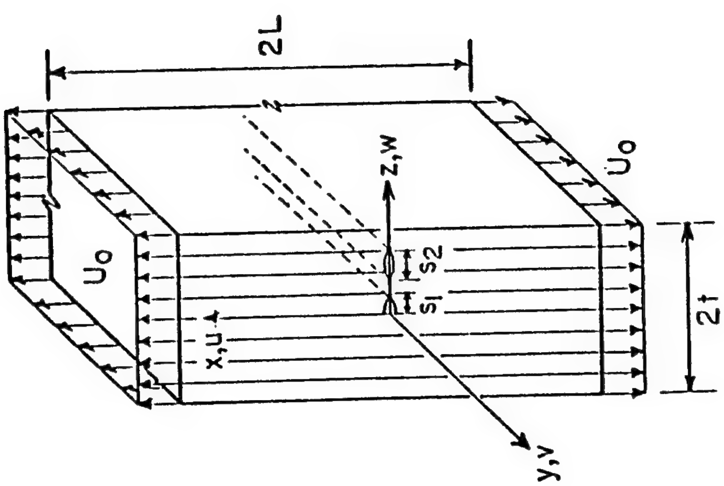


No. of cycles vs. attenuation for cyclic-tension-tension test for type II specimen (2649#8, 40 ksi).

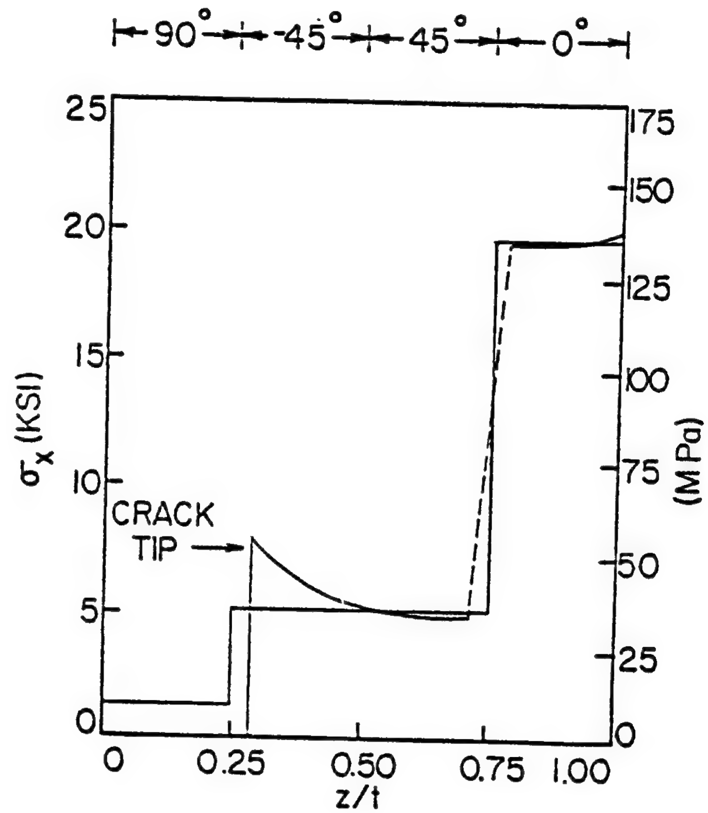


Number of cracks along the edge of a type II specimen cycled at a maximum stress of 40 ksi.

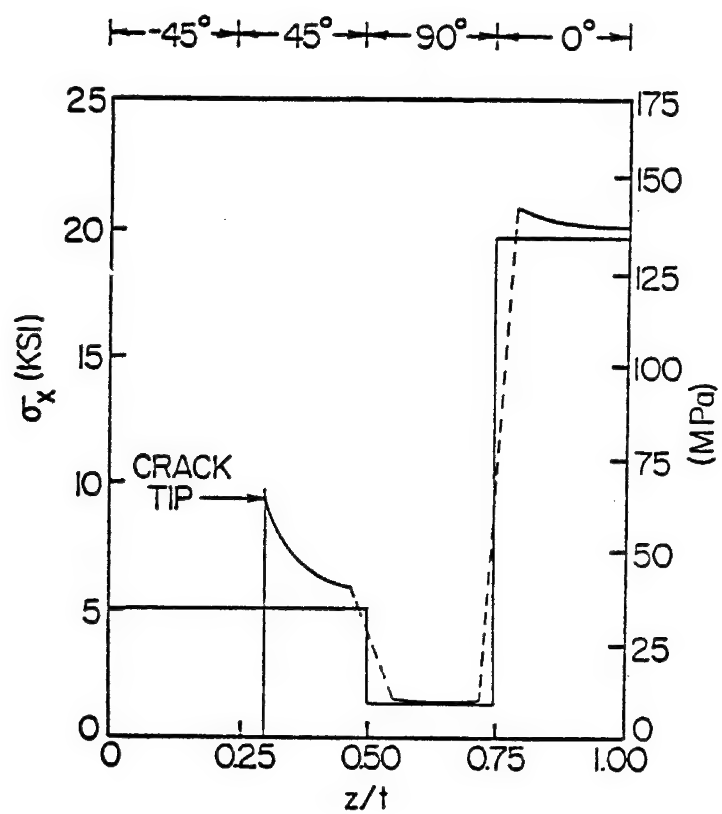




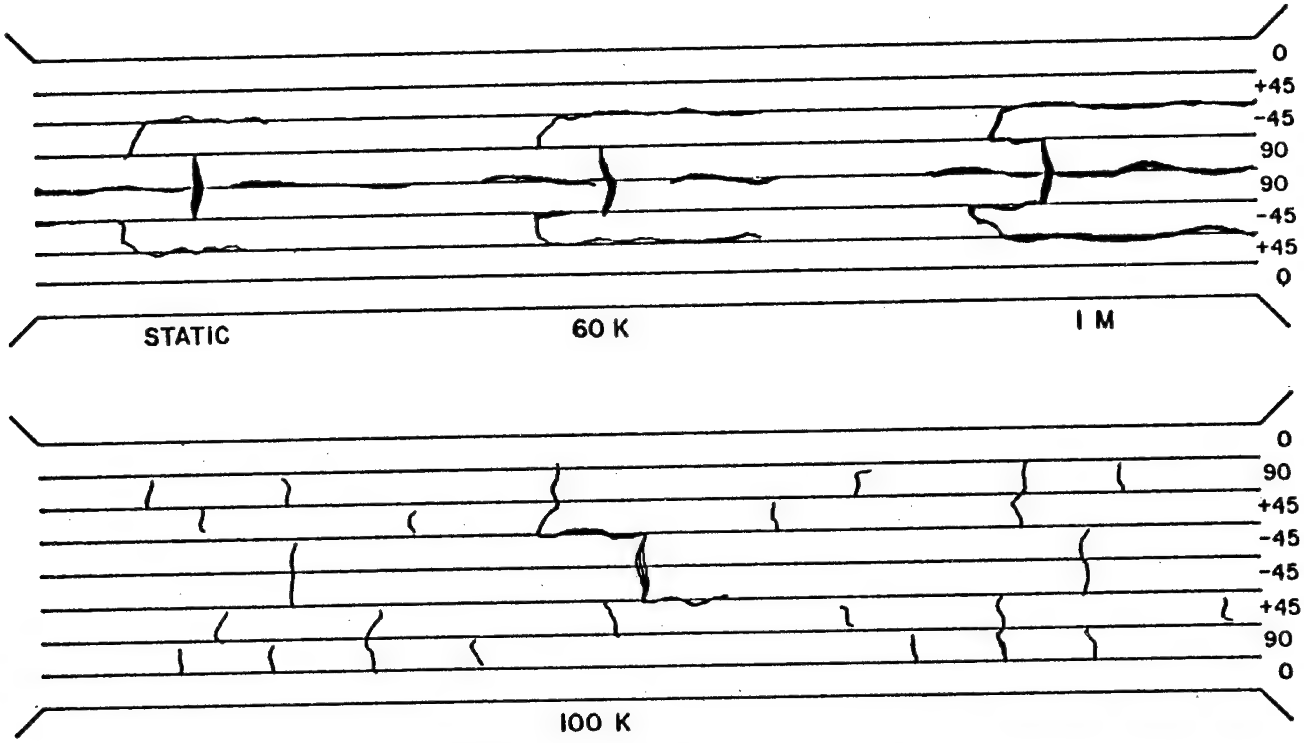
Schematic diagram of geometry of cracked laminate analyzed



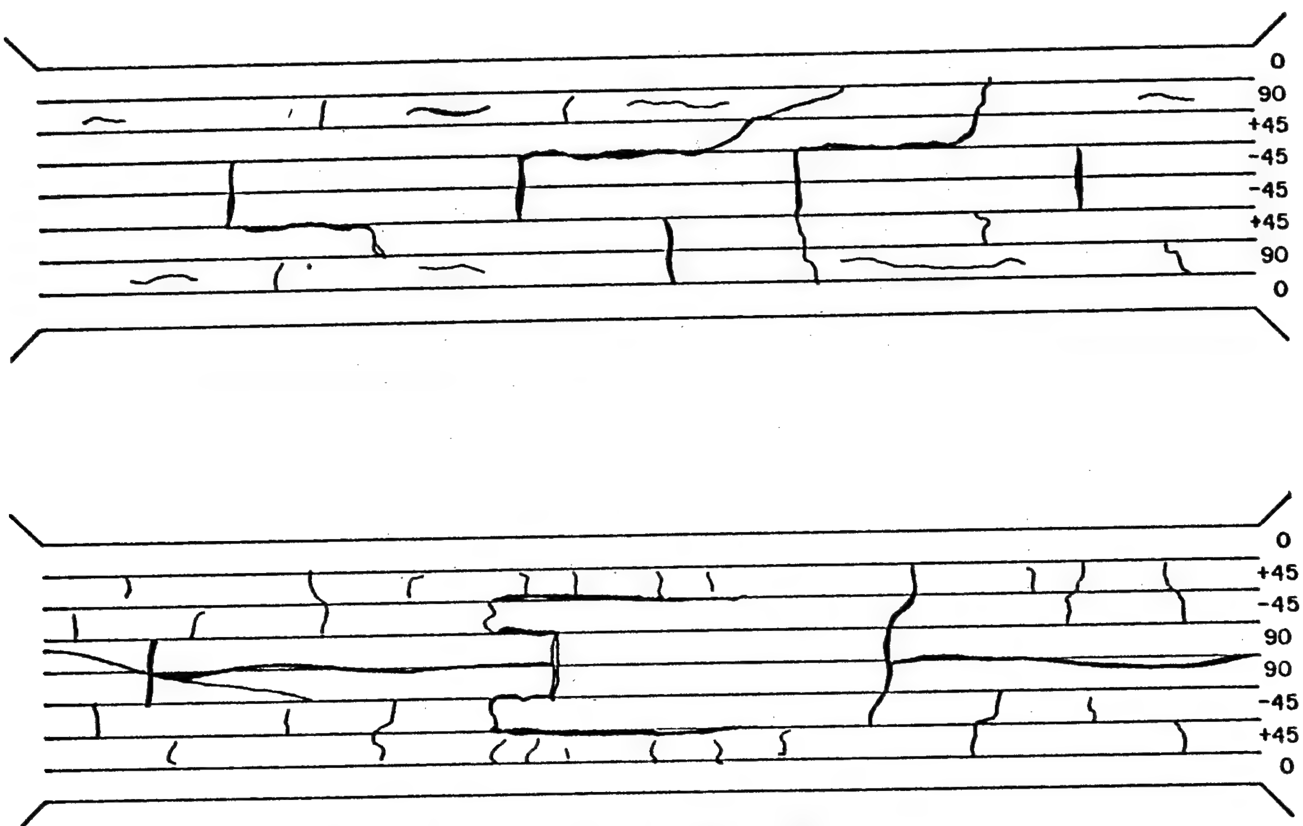
Distribution of axial normal stress as a function of the thickness position for a type I laminate



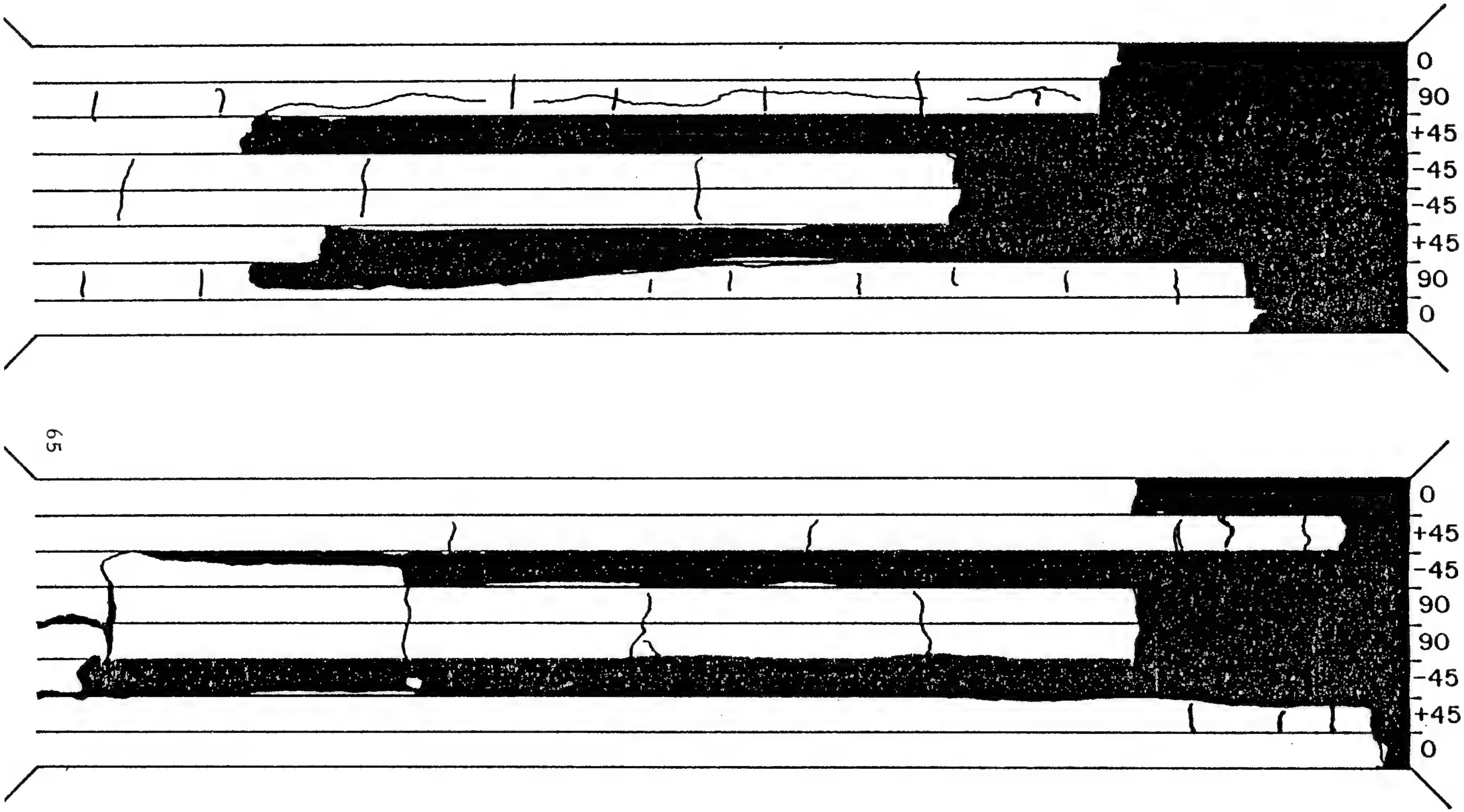
Distribution of axial normal stress as a function of the thickness position for a type II laminate



Damage patterns in the region of fracture for a Type I and Type II laminate, at moderate cyclic stress levels



PRE-FRACTURE PATTERNS NEAR FRACTURE SITE



FRACTURE PATTERNS

SUMMARY OF COMPLETED ACTIVITY

1. THE PRECISE NATURE OF "FIRST PLY FAILURE" HAS BEEN DETERMINED.
2. THE EFFECT OF THERMAL RESIDUAL STRESS ON "FIRST PLY FAILURE" HAS BEEN PREDICTED AND DEMONSTRATED.
3. A CHARACTERISTIC DAMAGE STATE HAS BEEN IDENTIFIED AND PREDICTED ANALYTICALLY.
4. AN EFFECT OF STACKING SEQUENCE ON THE INTERNAL STRESS DISTRIBUTIONS IN THE DAMAGED CONDITION HAS BEEN IDENTIFIED.
5. AN EXTENSIVE RECORD OF INTERNAL DAMAGE, RESIDUAL STRENGTH, AND LIFE AS A FUNCTION OF LOAD HISTORY HAS BEEN COLLECTED.
6. A ONE DIMENSIONAL CLOSED FORM SOLUTION AND A THREE DIMENSIONAL FINITE DIFFERENCE SOLUTION FOR STRESSES AROUND INTERNAL DAMAGE HAVE BEEN COMPLETED.
7. THE DEPENDENCE OF THE FINAL FRACTURE PROCESS ON STACKING SEQUENCE HAS BEEN INVESTIGATED.
8. THE EFFECT OF INITIAL DEFECTS HAS BEEN STUDIED.
9. SEVERAL DAMAGE MECHANISMS HAVE BEEN IDENTIFIED.
10. A NEW ULTRASONIC TECHNIQUE HAS BEEN DEVELOPED WHICH IS EXTREMELY SENSITIVE TO THE DEVELOPMENT OF INTERNAL DAMAGE.
11. A NEW VIDEO-THERMOGRAPHY TECHNIQUE CALLED VIBROTHERMOGRAPHY HAS BEEN DEVELOPED FOR THE DETECTION AND ANALYSIS OF COMPLEX DAMAGE IN COMPOSITE MATERIALS.
12. THE TECHNIQUE OF REPLICATION HAS BEEN ADAPTED TO COMPOSITE MATERIALS ENABLING PERMANENT RECORDS OF SURFACE DAMAGE DETAIL TO BE QUICKLY RECORDED TO FACILITATE DAMAGE DEVELOPMENT STUDIES.
13. CLOSED CIRCUIT COLOR TELEVISION (VIDEO) RECORDINGS OF TEN-COLOR ISOTHERM VIDEO-THERMOGRAPHY PATTERNS HAVE BEEN USED TO INVESTIGATE THE DYNAMIC NATURE OF FRACTURE EVENTS, TO IDENTIFY THE POINT OF FRACTURE INITIATION AND THE NATURE OF THE ENERGY RELEASE DURING THE FRACTURE EVENT, FOR EXAMPLE.

CHARACTERIZATION OF FATIGUE DAMAGE

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UNIVERSITY OF DAYTON RESEARCH INSTITUTE

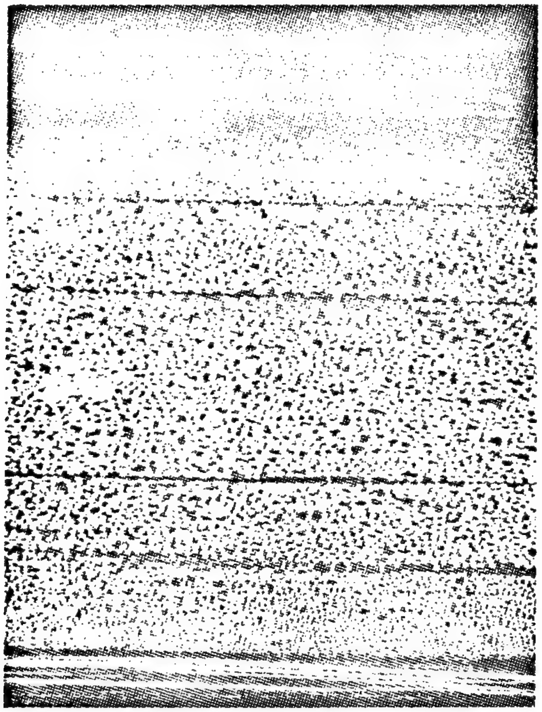
OBJECTIVE:

TO CHARACTERIZE FATIGUE DAMAGE OF COMPOSITE LAMINATES UNDER CYCLIC LOADINGS AND ESTABLISH A SUITABLE WORKING FORMULA FOR PREDICTION OF FATIGUE LIFE.

- CRACK DENSITY
- MODULUS CHANGE
- RESIDUAL STRENGTH
- ACOUSTIC EMISSION
- DENSITY

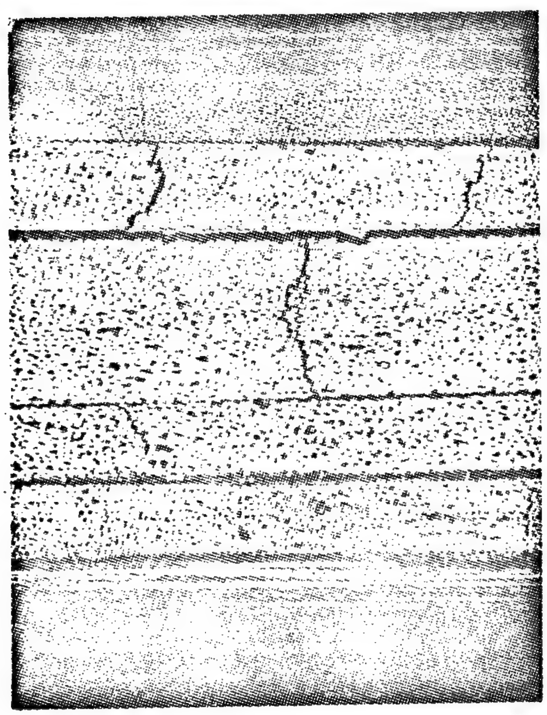
SUMMARY:

- MOST OF TRANSVERSE CRACKS DEVELOPED IN EARLY FATIGUE CYCLE AND THEREAFTER MOST OF FATIGUE CYCLES APPEAR TO BE SPENT FOR DELAMINATION.
- STRONG INDICATION OF CORRELATION BETWEEN CRACK DENSITY AND FATIGUE LIFE, AND CRACK DENSITY APPROACHES TO A CONSTANT VALUE AT NEAR THE END OF FATIGUE LIFE.
- LINEAR RELATIONSHIP BETWEEN MODULUS RATIO, E_n/E_0, AND FATIGUE LIFE EXCEPT AT EARLY FATIGUE CYCLE. THE RATIO OF E_n AND E_o DECREASED AS S_{max} DECREASED.



Before fatigue

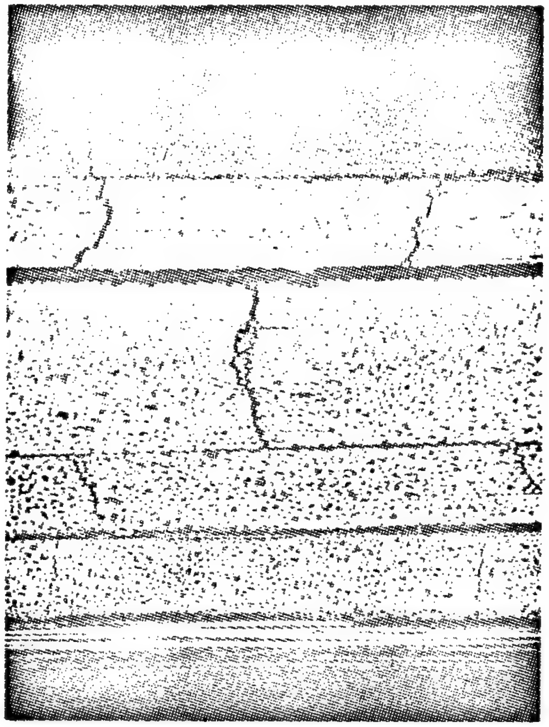
100,000 cycle



150,000 cycle

200,000 cycle

Figure 1. Phomicrographs showing fatigue damage: graphite/epoxy T300/5208 $[0/90\pm45]_s$, S_{max} = 50Ksi, 10Hz, R = 0.1



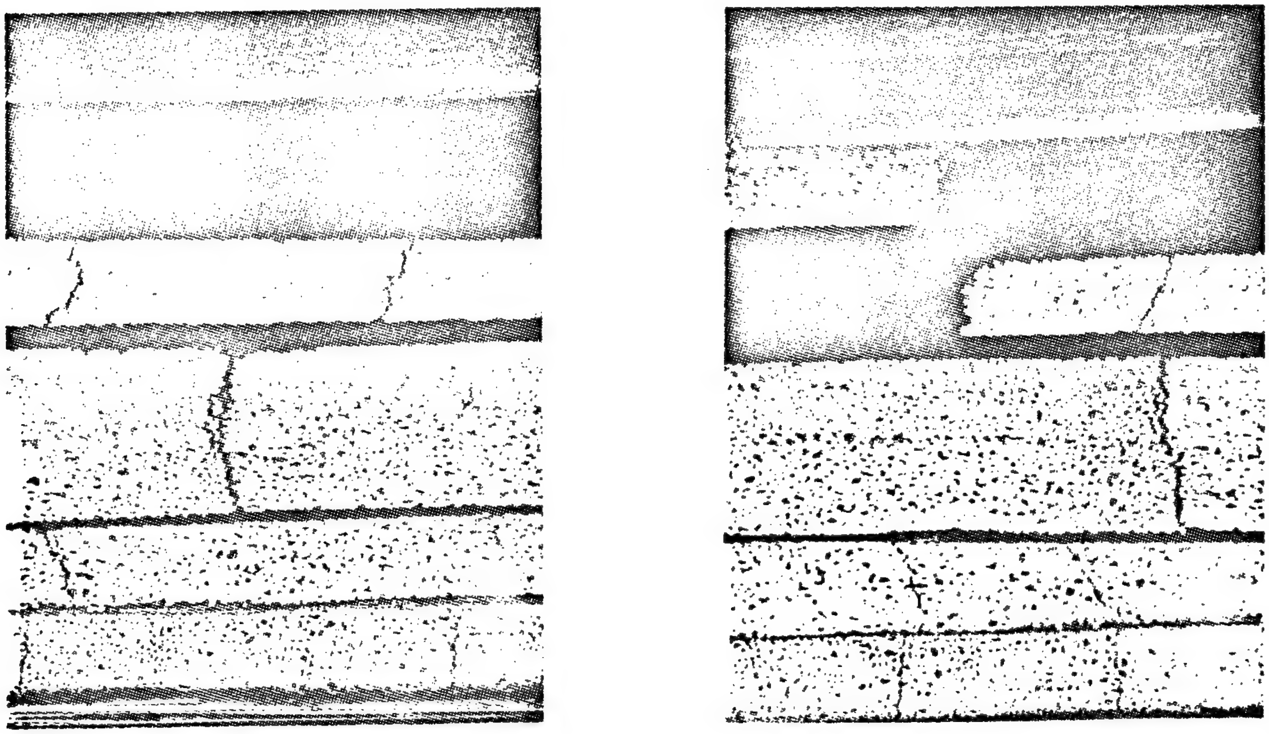
250,000 cycle

350,000 cycle

450,000 cycle

550,000 cycle

Figure 1 (Continued)



650,000 cycle

650,000 cycle
(50 mil from spot #1)

Figure 1 (Continued)

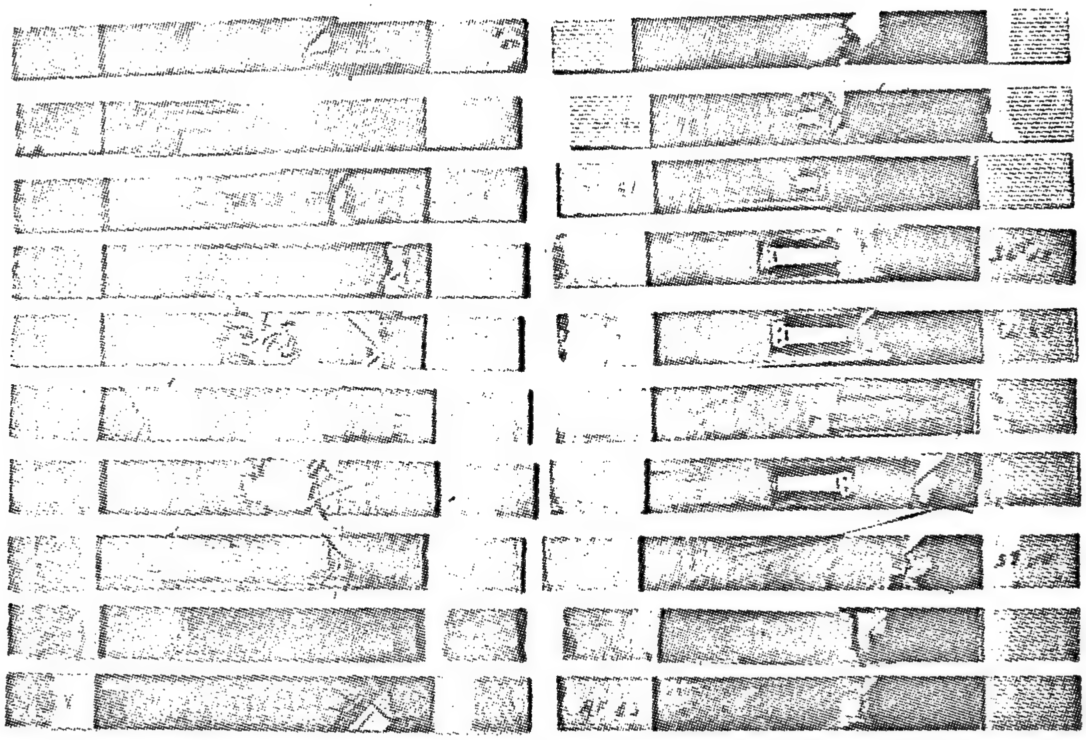


Figure 2. Fatigue failure modes of graphite/epoxy T300/5208 $[0/90/\pm45]_s$, S_{max} = 50 Ksi, 10 Hz, R = 0.1

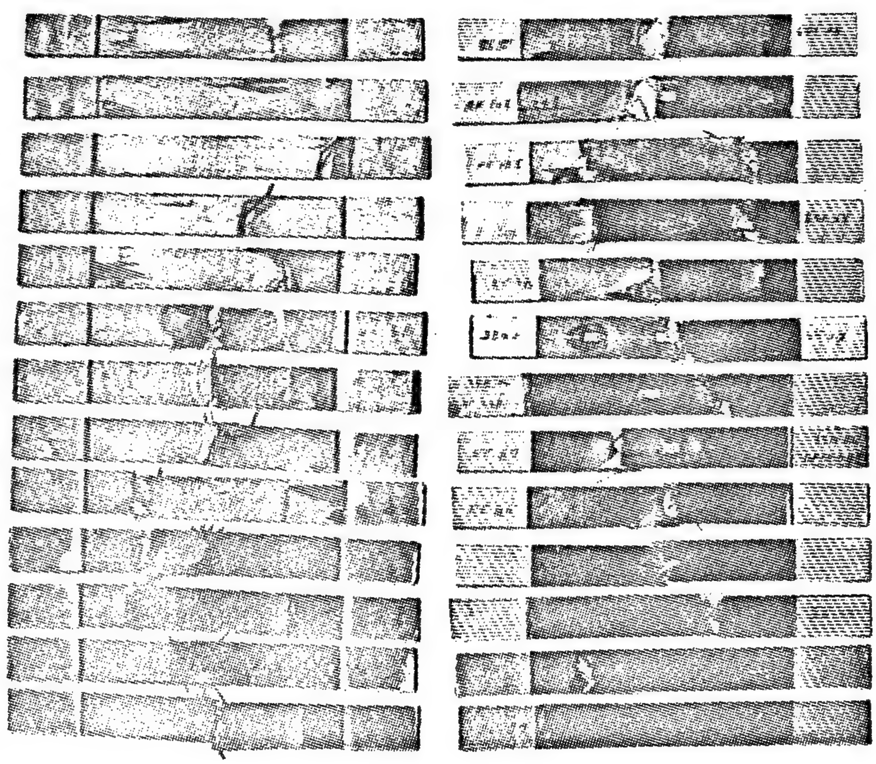


Figure 3. Fatigue failure modes of graphite/epoxy T300/5208 $[0/90/\pm45]_s$, S_{max} = 60 Ksi, 10 Hz, R = 0.1

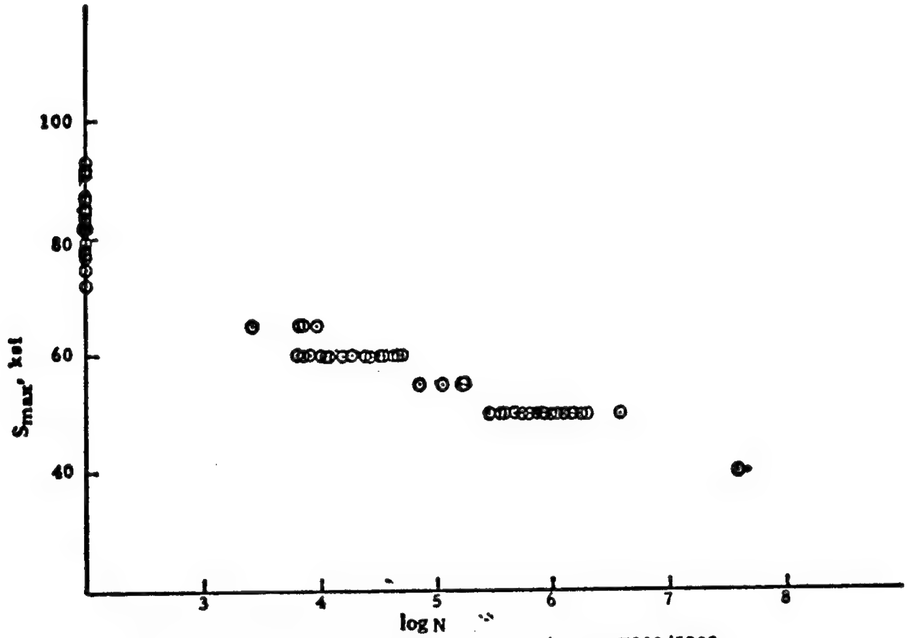


Figure 4. S-N relationships for graphite/epoxy T300/5208 $[0/90/\pm45]_s$, 10Hz, R = 0.1

Specimen	σ_{max}, ksi	Life, cycle
⊙ RF - 82	50	793,840
⊡ RF - 81	50	704,870
● RF - 83	60	37,560
■ RF - 85	60	52,360
▲ RF - 86	60	23,090
♦ RF - 87	60	24,570
× RF - 84	40	60,000,000 (Estimated)

PANEL 2

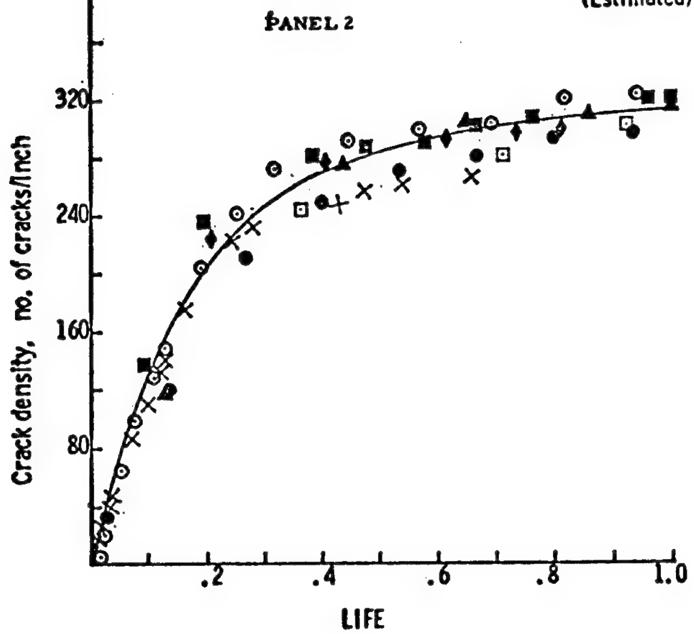


Figure 5. Crack density vs. fatigue life for Graphite/Epoxy T300/5208, $[0/90/\pm45]_s$

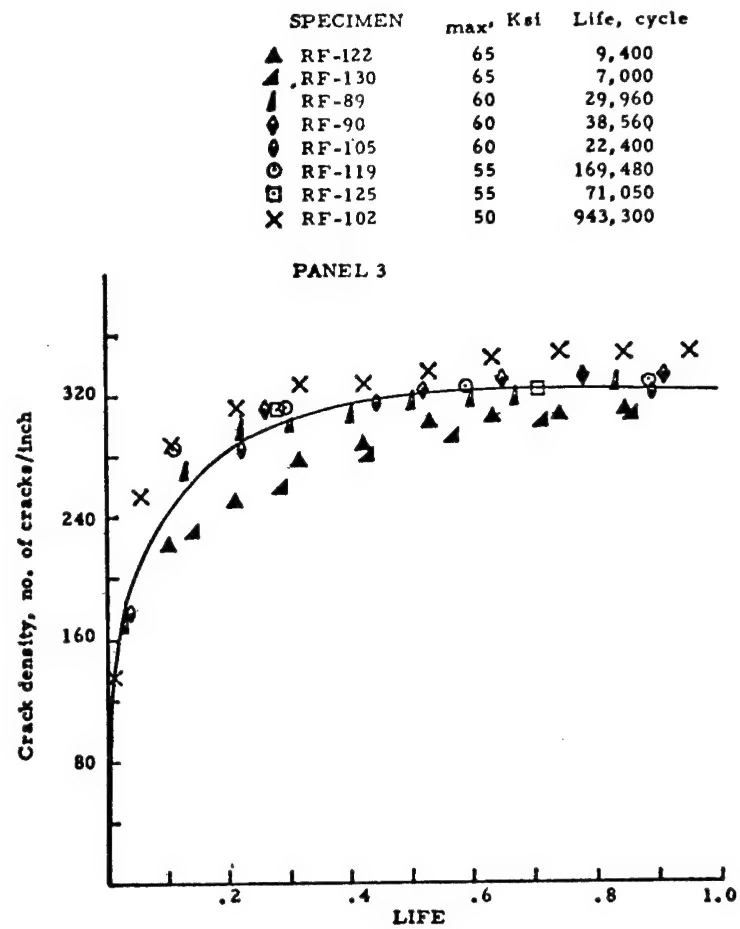


Figure 6. Crack density vs fatigue life for graphite/epoxy T300/5208, $[0/90/\pm45]_s$

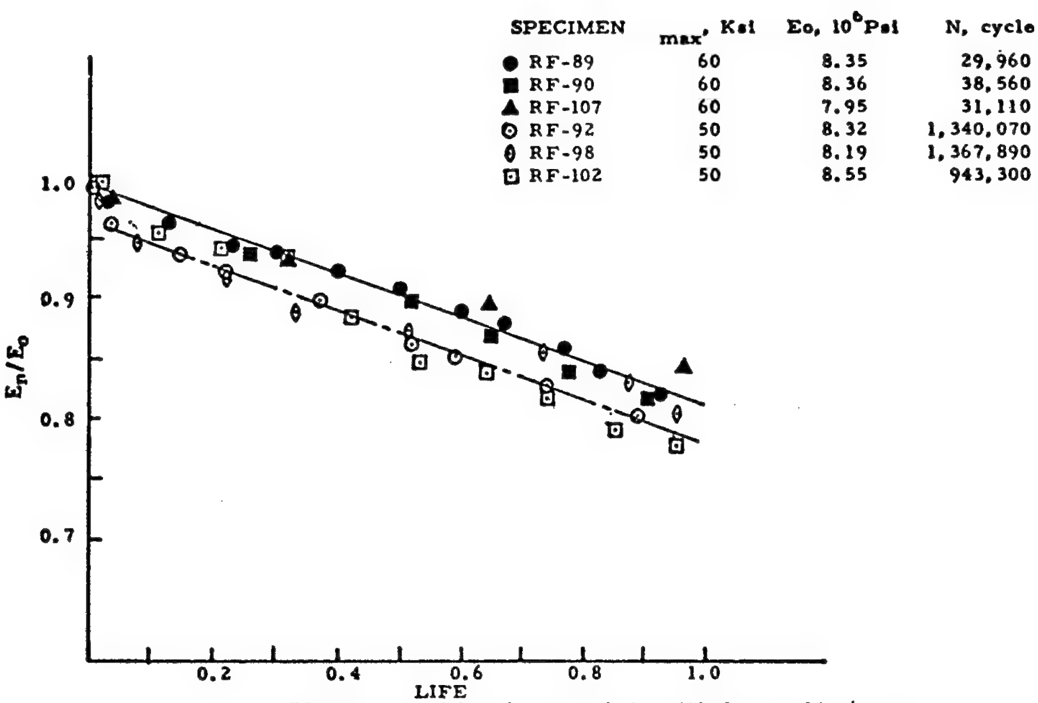


Figure 7. Modulus change vs fatigue life for graphite/epoxy T300/5208, $[0/90/\pm45]_s$

TORSION TEST TO DETERMINE

TRANSVERSE SHEAR MODULUS, G_{23}

N. J. PAGANO

F. K. HUBER

OBJECTIVE

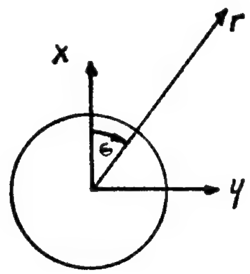
DEVELOP AN EXPERIMENTAL APPROACH FOR DETERMINING TRANSVERSE SHEAR MODULUS, G_{23}

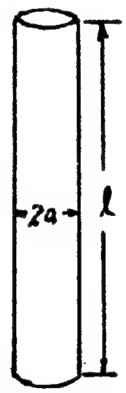
APPROACH

- SOLVE FOR G_{23}, IN TERMS OF EXPERIMENTALLY OBTAINABLE QUANTITIES
- DEVELOP TEST TO OBTAIN REQUIRED VALUES
- VALIDATE OBTAIN MODULUS

CONCLUSIONS

- PRELIMINARY TESTING INDICATES GOOD AGREEMENT WITH PUBLISHED DATA
- STRAIN GAGE SIZE AND ALIGNMENT MUST BE FURTHER ANALYZED
- EFFECT OF VARIATIONS IN GRIP GEOMETRY MUST BE STUDIED





Applying B. C. for pure torsion and orthotropic material properties the Generalized Nooke's law reduces:

$$\begin{aligned} \tau_{xz} &= G_{12}\,\gamma_{xz} \\ \tau_{yz} &= G_{23}\,\gamma_{yz} \end{aligned} \tag{1}$$

From elastic solution

$$\begin{aligned} \tau_{xz} &= \frac{-T}{J}y \\ \tau_{yz} &= \frac{Tx}{J} \\ (J &= \frac{\pi}{2}a) \end{aligned} \tag{2}$$

Combining (1) & (2)

$$\begin{aligned} G_{12} &= \left(\frac{-T}{J}y\right)\left(\frac{1}{\gamma_{yz}}\right) \\ G_{23} &= \left(\frac{T}{J}x\right)\left(\frac{1}{\gamma_{yz}}\right) \end{aligned} \tag{3}$$

Expressing (1, 2, 3) in cylindrical coordinates

$$\begin{aligned} \tau_{rz} &= 0, \quad \tau_{z_\theta}\ \frac{Tr}{J} \\ \gamma_{z\theta} &= \frac{Tr}{J}\left(\frac{\sin^2\theta}{G_{12}} + \frac{\cos^2\theta}{G_{23}}\right) \\ \gamma_{rz} &= \frac{Tr}{J}\left(\frac{1}{G_{23}} - \frac{1}{G_{12}}\right)\sin\theta\cos\theta \end{aligned} \tag{4}$$

Therefore, G_{23} and G_{12} are known if T, θ, $\gamma_{z\theta}$, γ_{rz} are known.

Strain-displacement relations yield

$$u = \alpha yz + C_1 y + C_2 z + C_3$$

$$v = \alpha xz - C_1 x + C_4 z + C_5 \tag{5}$$

$$w = Qxy - C_2 x - C_4 y + C_6$$

$$\alpha = \frac{T}{2J}\left(\frac{1}{G_{23}} + \frac{1}{G_{12}}\right)$$

$$Q = \frac{T}{2J}\left(\frac{1}{G_{23}} - \frac{1}{G_{12}}\right)$$

$C_1 \cdots C_b$ are rigid motion constants and vanish

$$u = -\alpha yz$$

$$v = \alpha xz \tag{6}$$

$$w = Qxy$$

expressing in cylindrical coordinates

$$u_r = 0$$

$$u_\theta = \alpha rz \tag{7}$$

$$w = Qr^2 \sin\theta \cos\theta$$

Aligning fibers to X axis

at $r = a$, $z = 0$, $\theta = 0, \pi/2, \pi, 3/2\pi$

$$u_r = 0$$

$$u_\theta = 0$$

$$w = 0$$

at $r = a$ $\theta = 0, \pi/2, \pi, 3/2\pi$, $z = 1$

$$u_r = 0$$

$$u_\theta = \alpha a l$$

$$w = 0$$

Therefore if load is introduced at these 8 points the assumed strain distribution will be present in the test specimen.

STATISTICAL FAILURE ANALYSIS OF COMPOSITE MATERIALS

by

Pei Chi Chou
A. S D Wang
Robert Croman

Drexel University

Viewgraphs for presentation at the Fourth Mechanics of Composite Review
Oct 31 - Nov 2 1978

Dayton Ohio

OBJECTIVES

1. Residual Strength in Fatigue

   — to establish strength degradation, or strengthening, models based on experimental data, and statistical methods.

2 Proof-tests — to investigate the relationship between static strength and fatigue life; guaranteed strength and life after proof-testing.

3. Development of Statistical Tools for Composite Failure Applications:

   - Censoring in Fatigue Tests
   - Modified 3-parameter Weibull Distribution
   - Bi-linear Weibull Distribution

CONCLUSIONS

1. An equation of the residual strength as a function of fatigue cycles is found. This equation can be fitted to experimental data that show either monotonic degradation of residual strength, or an early increase, then decrease of residual strength.

2. For the uni-directional graphite/epoxy composite tested here, the strength - life equal rank assumption seems to hold. Proof-testing can guarantee a minimum static strength; with slightly less degree of confidence, it can also guarantee fatigue life.

3. Certain statistical tools are recommended for the study of failure of composites. These include:

   - Censoring in fatigue test, which can yield the same amount of information with less tests.
     - A modified 3-parameter Weibull distribution that is most suited for reduced higher-percentile population and residual strength.
     - Bi-linear 2-parameter Weibull distribution fits best some fatigue data.

Degradation of Strength Equation for Individual Specimen

(1) Hahn - Yang Model

$$y = x - f(S)\, n$$

$x = (\text{static strength})^{\alpha}$, $n = (\text{no. of cycles})^{\alpha_1}$
$y = (\text{residual strength})^{\alpha}$, $S = (\text{max. fatigue stress})^{\alpha}$

- No open parameters ($f(S)$ fixed by strength and life)

(2) Chou + Croman (April 1978)

$$\frac{x-y}{x-S} = \left(\frac{n}{n_\gamma}\right)^{i}$$

$n_\gamma = (\text{fatigue life})^{\alpha_1}$

- One open parameter, i

(3) Present Model

$$\frac{x-y}{x-S} = K\left[\frac{n}{n_\gamma}\right]^{i} + (1-K)\left[\frac{n}{n_\gamma}\right]^{j}$$

- Three open parameters — i, j, K
- Can represent increase and decrease in strength.

Static Strength and Fatigue Life Distribution Equations

(1) Static Strength Distribution

$$F_{R(0)}(x) = 1 - \exp(-x)$$

Non-dimensional static strength

$$x = \left(\frac{\text{static strength}}{\beta}\right)^{\alpha}$$

(2) Static Strength Distribution for $x > S$

$$F_{R(0)}(x) = 1 - \exp(-x + S)$$

(3) Fatigue Life Distribution

$$F_N(n) = 1 - \exp(-n)$$

Non-dimensional fatigue life

$$n = \left(\frac{\text{life}}{n_0}\right)^{\alpha_1}$$

Residual Strength Equation with Increase of Strength Capability

(1) Strength of Individual Specimen

$$\frac{x-y}{x-S} = K\left[\frac{n}{n_\gamma}\right]^i + (1-K)\left[\frac{n}{n_\gamma}\right]^j$$

(2) Distribution of Residual Strength

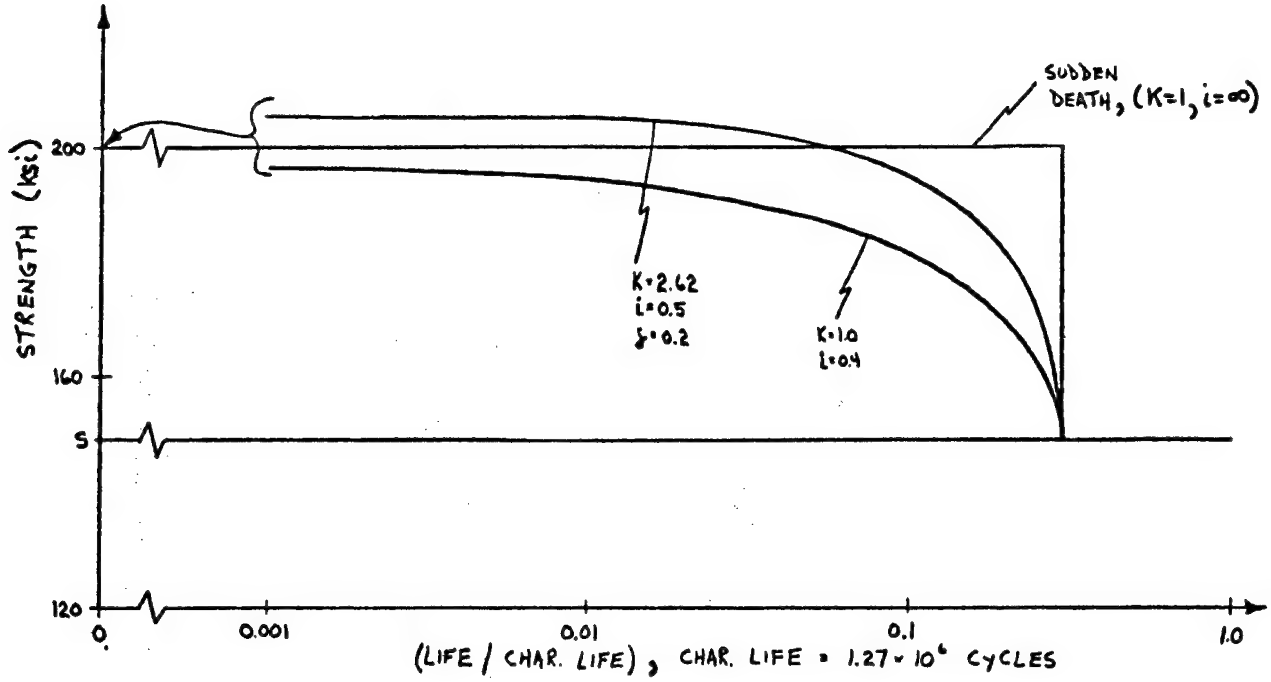
$$F_{R(n_{\gamma_1})}(y) = 1 - \exp[-x(y) + x_1]$$

(3) Mean of Residual Strength

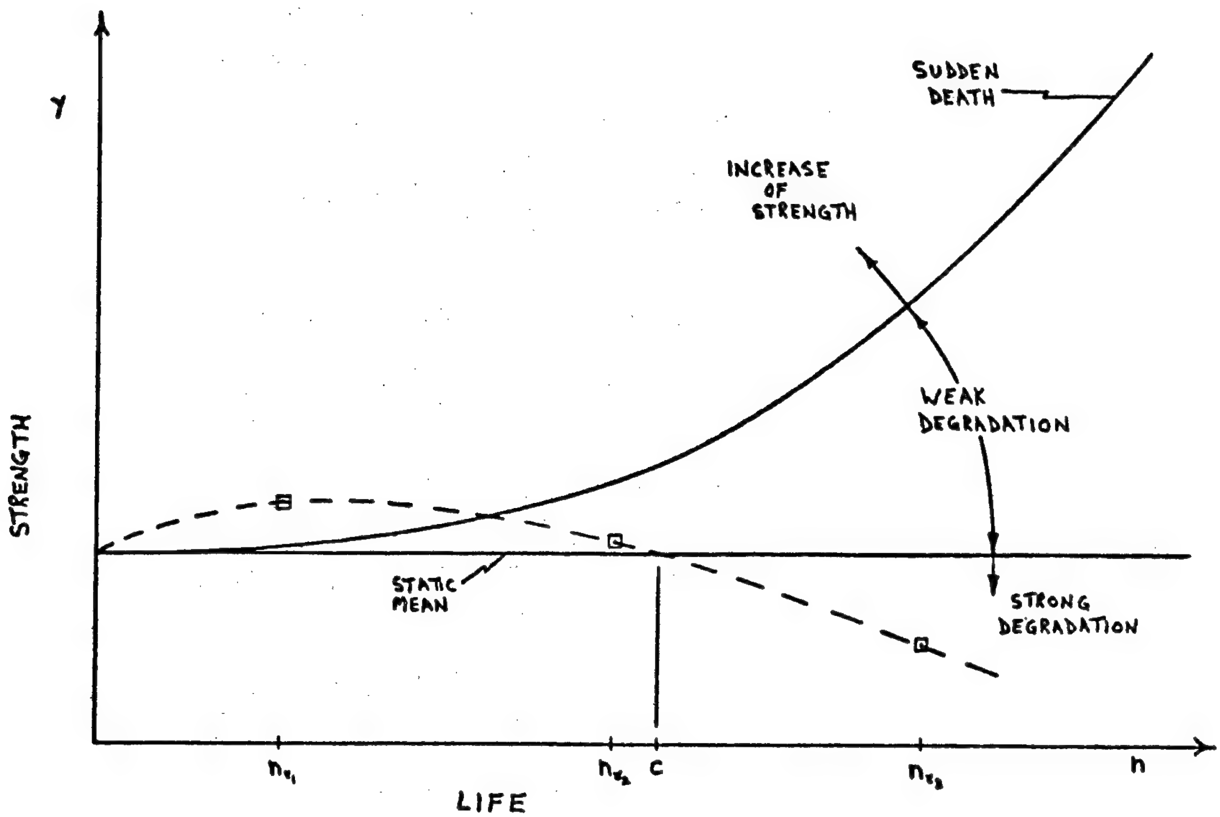
$$\mu_{R(n_{\gamma_1})} = \int_{x_1}^{\infty} \left\langle x - (x-S)\left\{K\left[\frac{n_{\gamma_1}}{x-S}\right]^i + (1-K)\left[\frac{n_{\gamma_1}}{x-S}\right]^j\right\}\right. \exp[-x+x_1]\,dx$$

n_{γ_1} = (residual strength test cycles)$^{\alpha_1}$

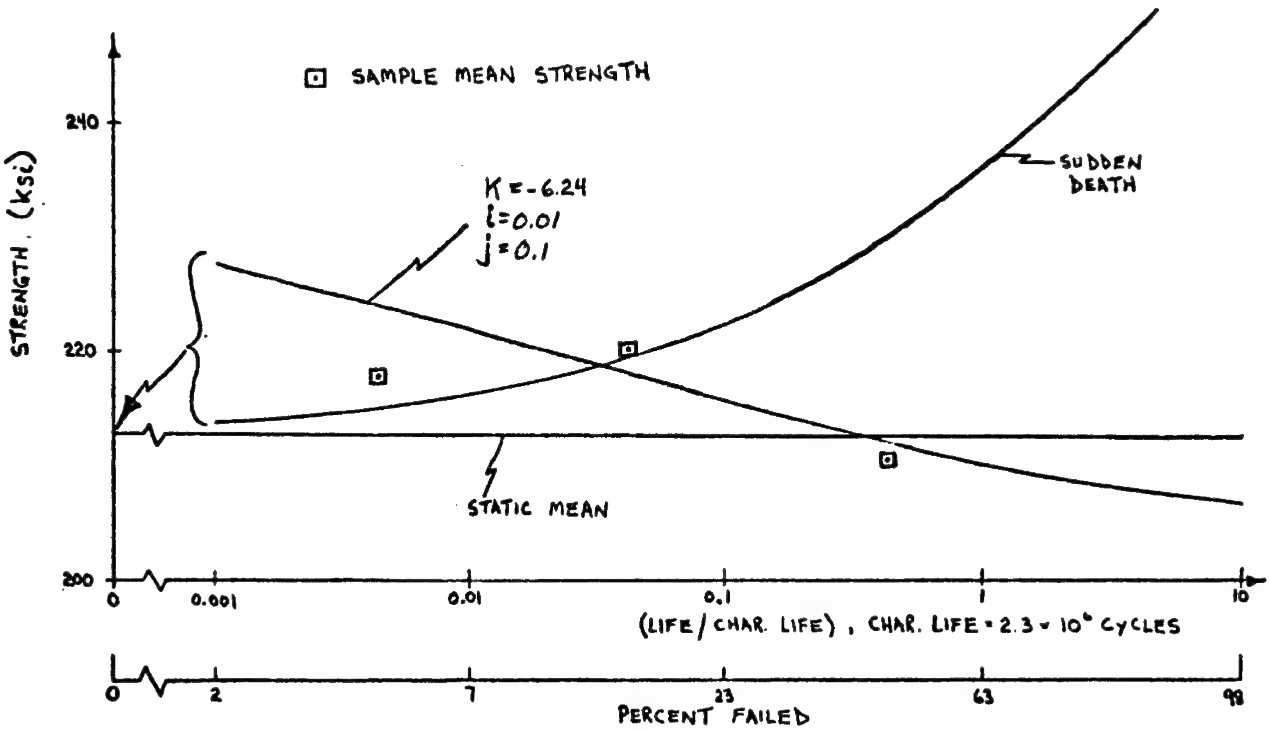
x_1 = (static strength)$^{\alpha}$ of specimen with $y = S$ at $n = n_{\gamma_1}$



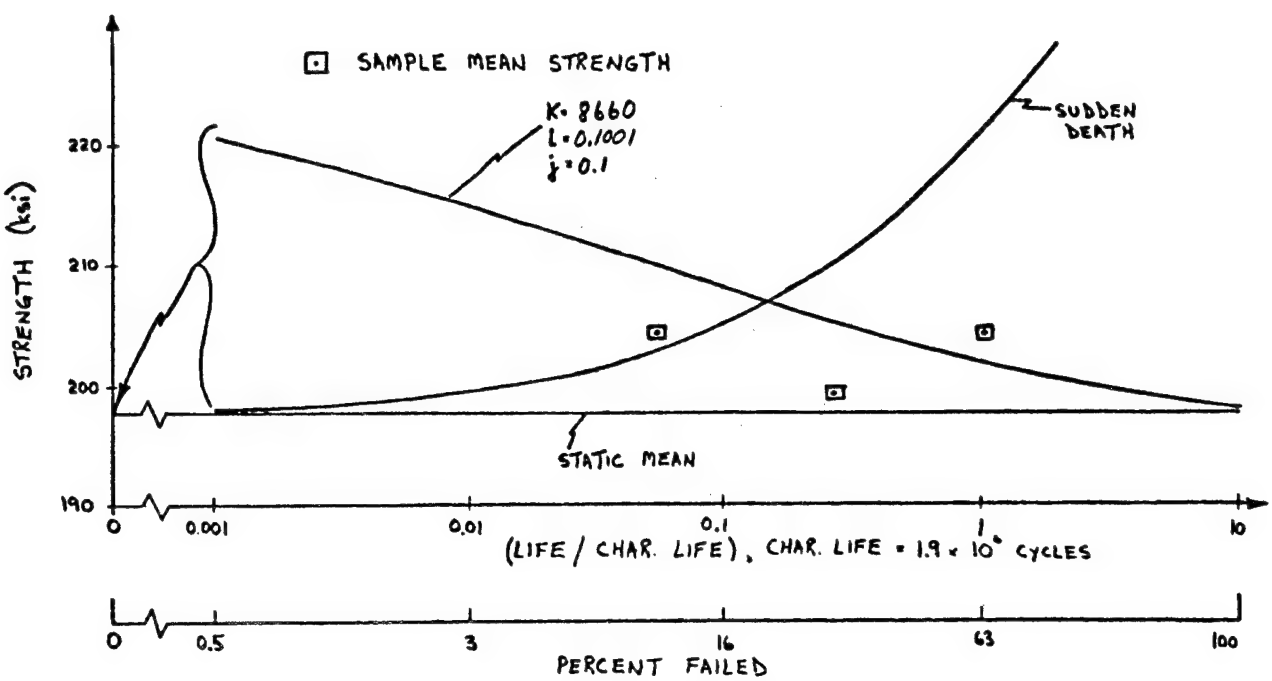
PLOT OF INDIVIDUAL SPECIMEN STRENGTH VS. LIFE FOR VARIOUS VALUES OF i, j, and K



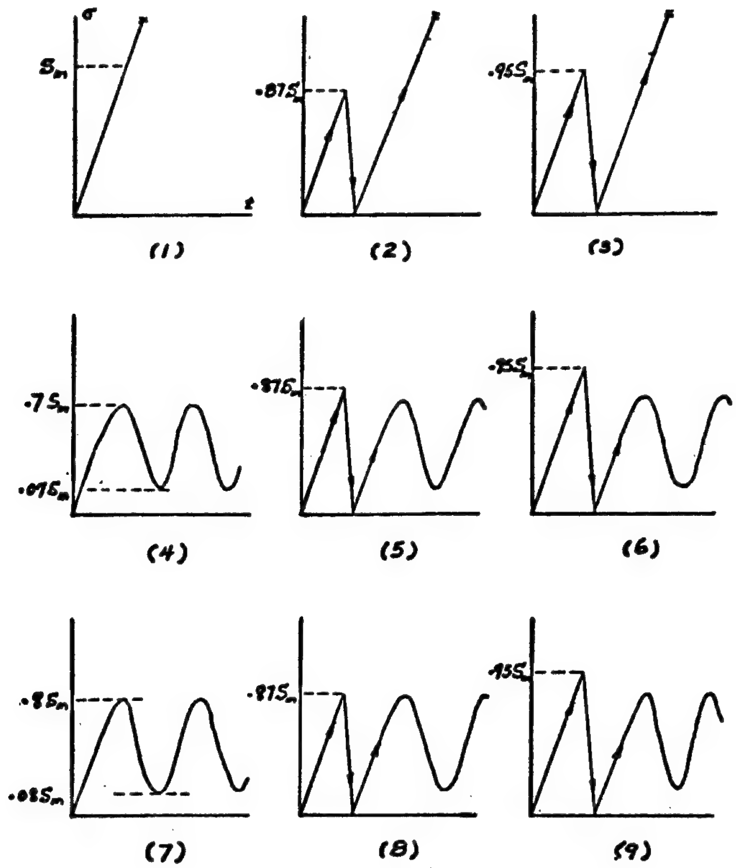
SCHEMATIC OF MEAN RESIDUAL STRENGTH VS. LIFE



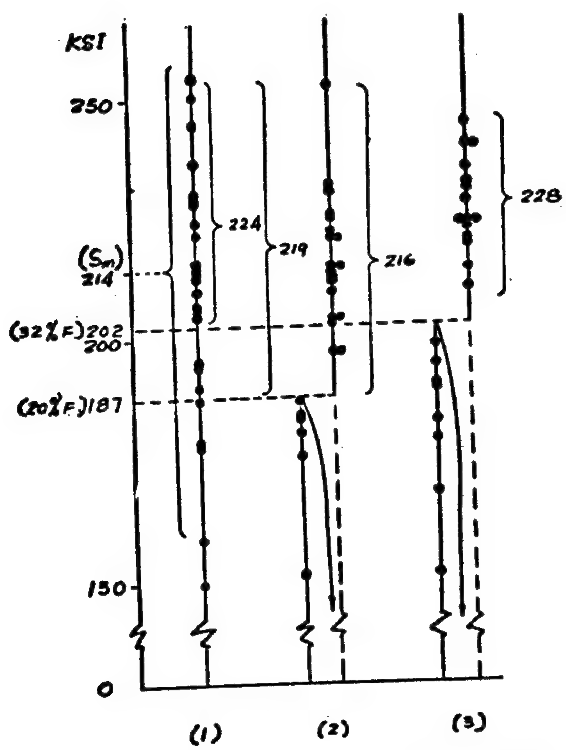
COMPARISON OF PREDICTED MEAN RESIDUAL STRENGTH WITH SAMPLE DATA FROM WANG



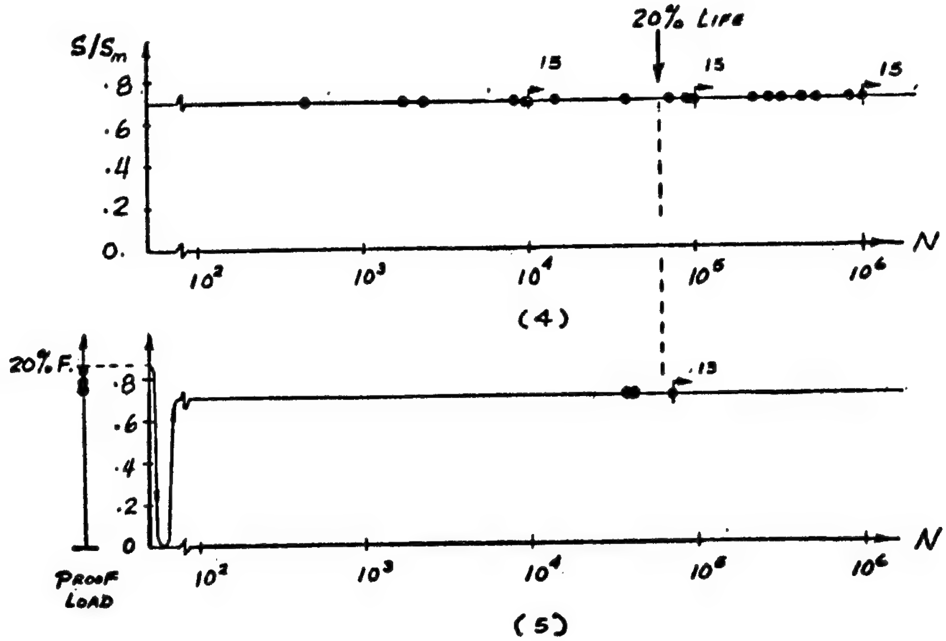
COMPARISON OF PREDICTED MEAN RESIDUAL STRENGTH WITH SAMPLE DATA FROM AWERBUCH-HAHN



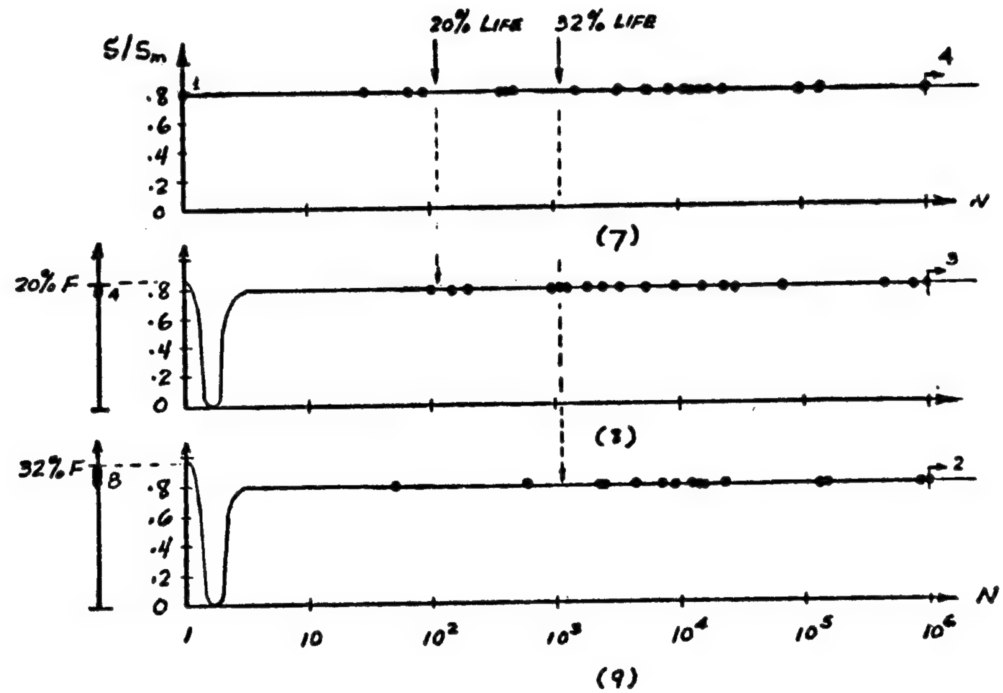
PROOF - TEST PROGRAM
. (25+ SPECIMENS EACH)
6 PLIES U.D AS-3501-06



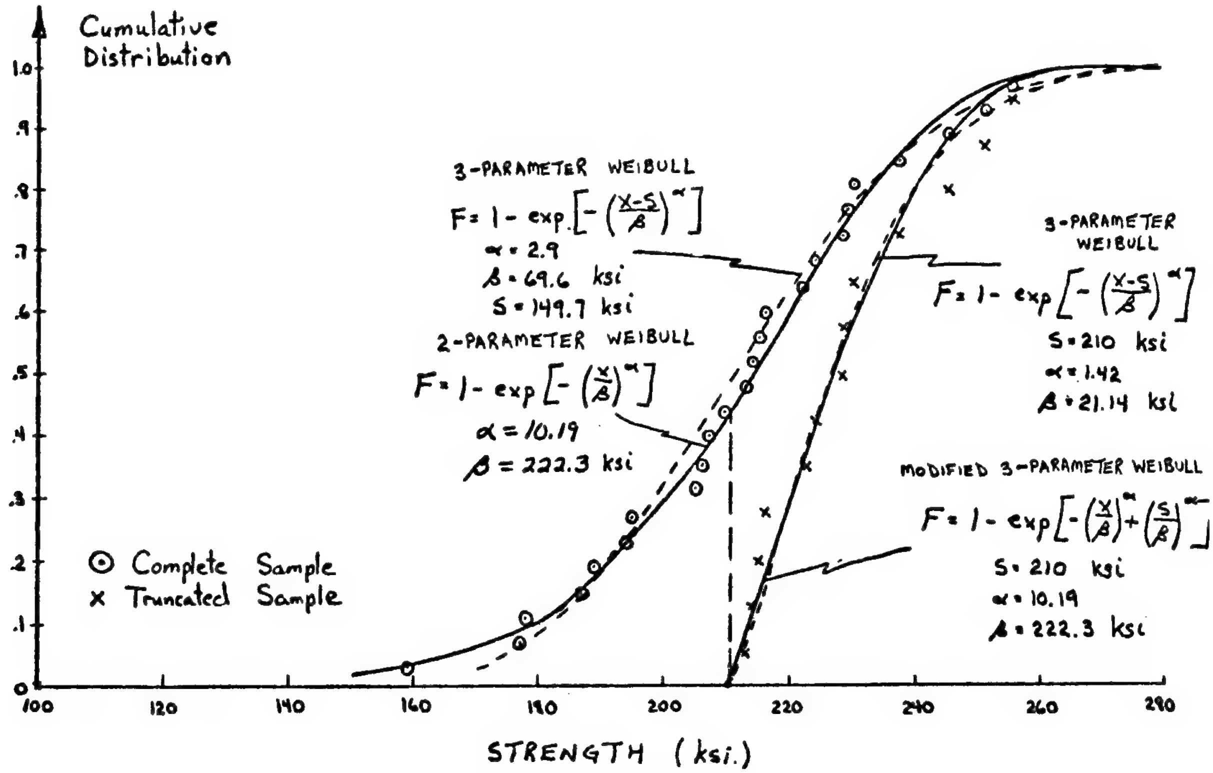
TENSILE STRENGTH DISTRIBUTION



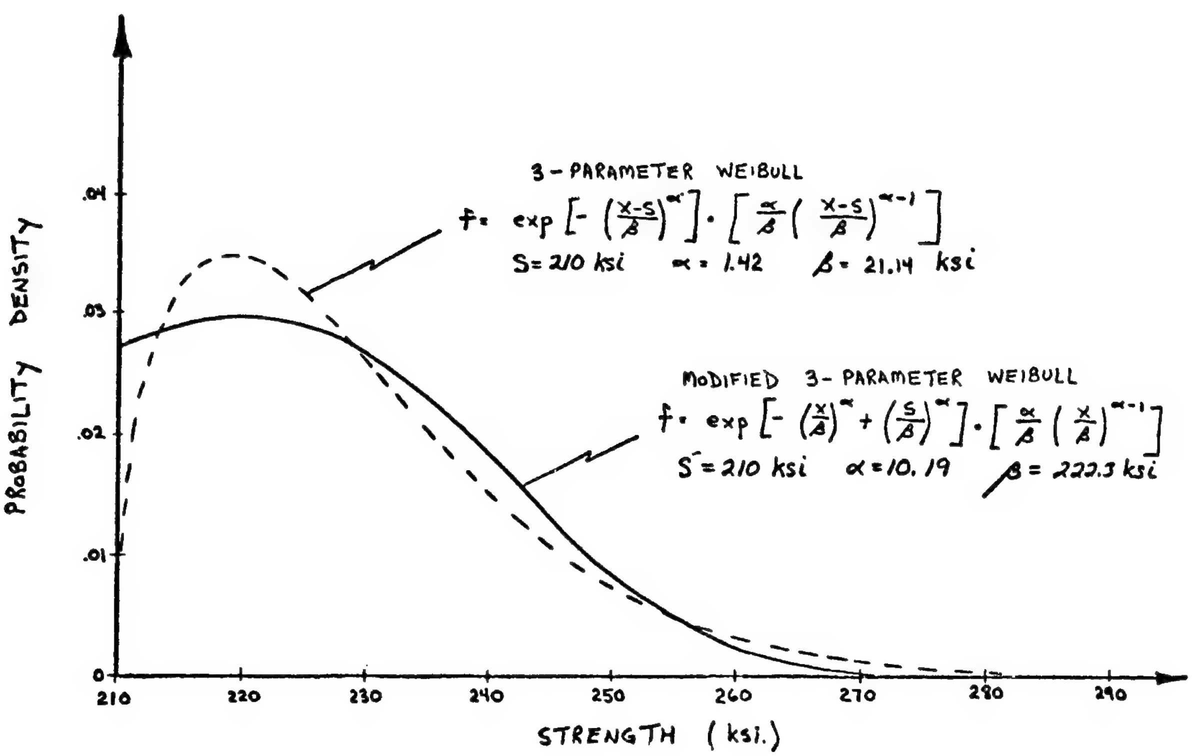
FATIGUE LIFE DISTRIBUTION.



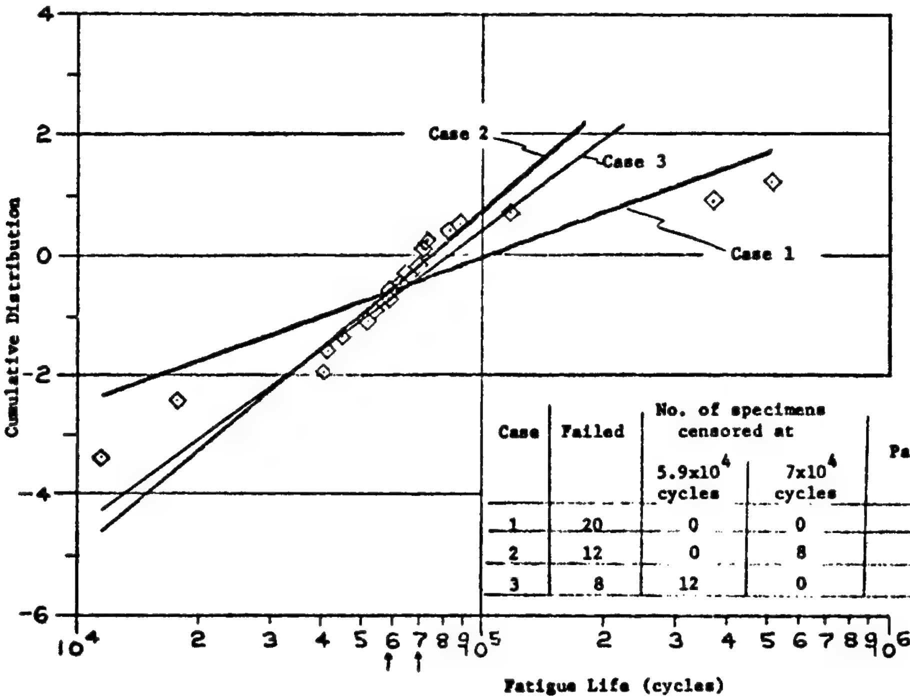
FATIGUE LIFE DISTRIBUTION



Cumulative Distribution Curves Fitted to Complete Sample Data and Truncated Sample Data.

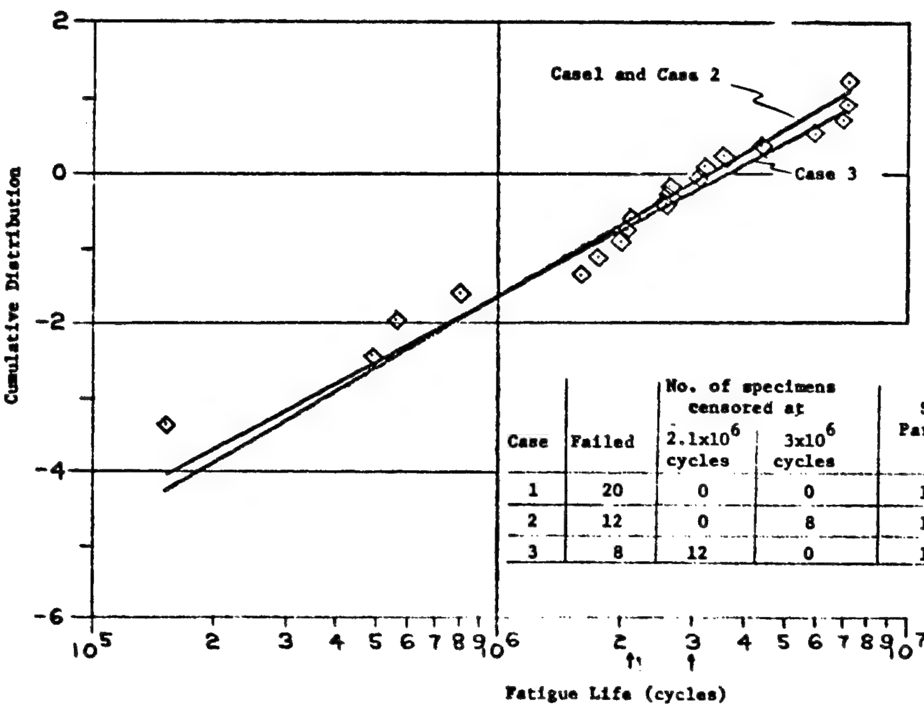


3- PARAMETER WEIBULL AND MODIFIED 3-PARAMETER WEIBULL DENSITY CURVES FOR TRUNCATED SAMPLE DATA.



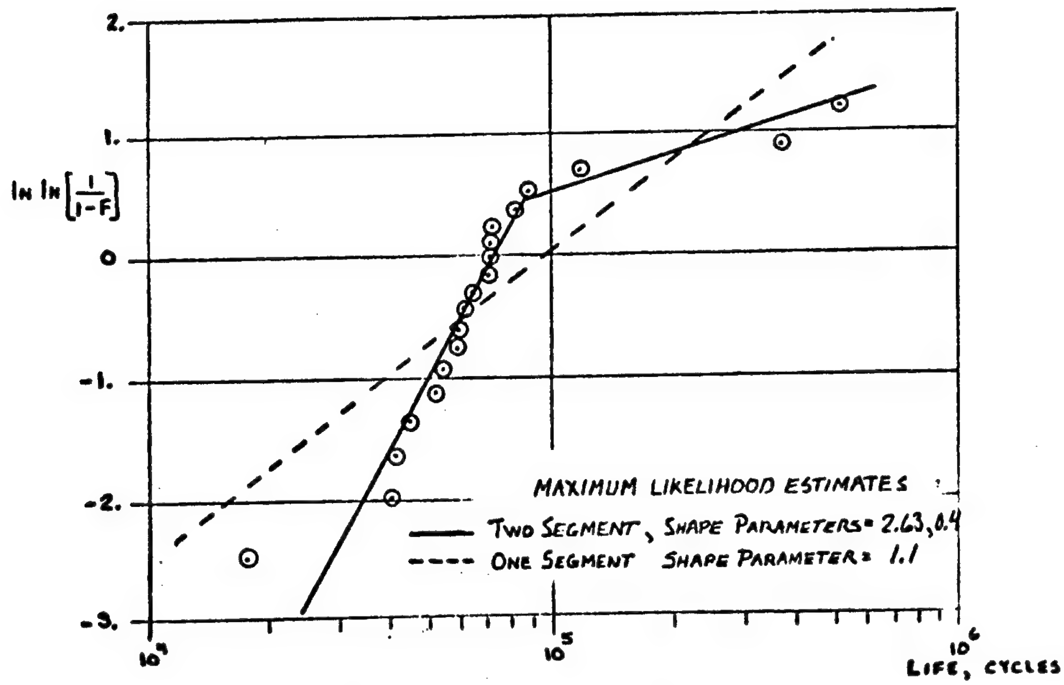
Case	Failed	No. of specimens censored at 5.9×10^4 cycles	No. of specimens censored at 7×10^4 cycles	Shape Parameter b	Scale Parameter N_A	Testing Time (Hrs.)
1	20	0	0	1.07	1.01×10^5	54.2
2	12	0	8	2.49	0.74×10^5	31.5
3	8	12	0	2.17	0.82×10^5	28.6

Cumulative Distribution Versus Fatigue Life Plot

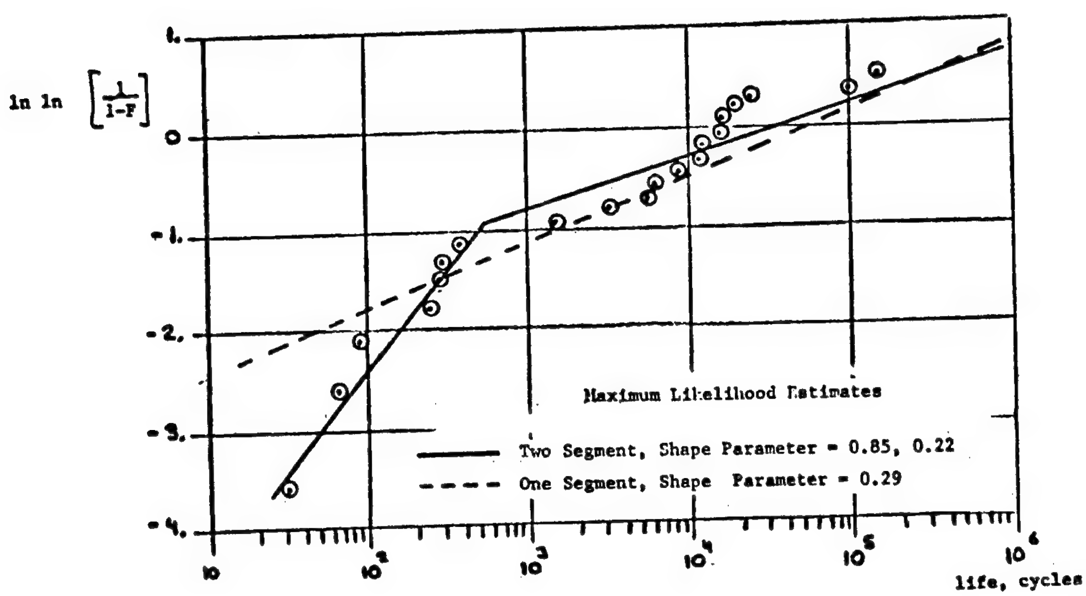


Case	Failed	No. of specimens censored at 2.1×10^6 cycles	No. of specimens censored at 3×10^6 cycles	Shape Parameter b	Scale Parameter N_A	Testing Time (Hrs.)
1	20	0	0	1.38	3.3×10^6	1690
2	12	0	8	1.39	3.3×10^6	1204
3	8	12	0	1.28	3.6×10^6	962

Cumulative Distribution Versus Fatigue Life Plot

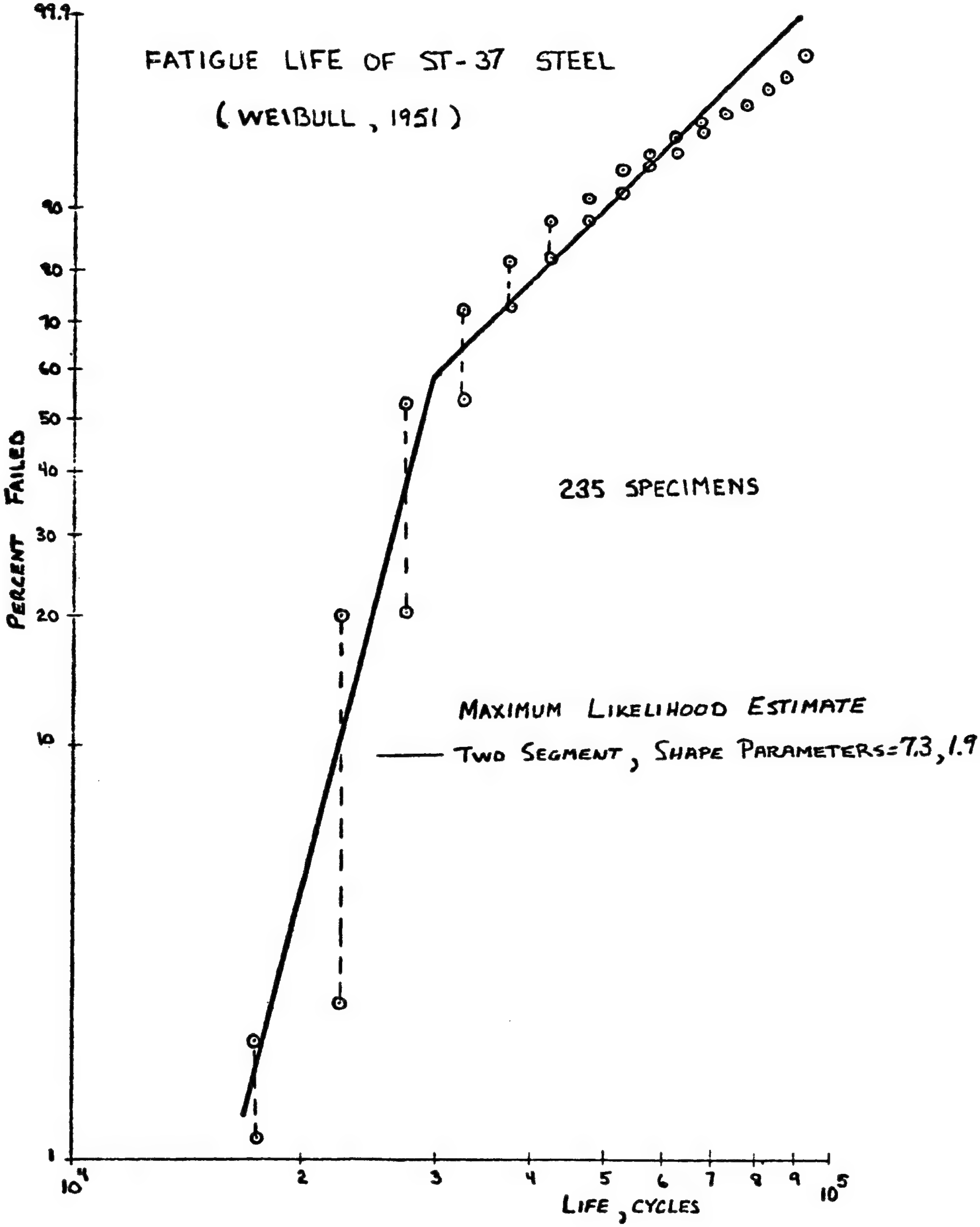


RYDER-WALKER LAMINATE I
TENSION-TENSION FATIGUE
(AFML-TR-76-241)



Present Study

Tension-Tension Fatigue of Unidirectional Graphite/Epoxy


FATIGUE LIFE OF ST-37 STEEL
(WEIBULL, 1951)
235 SPECIMENS
MAXIMUM LIKELIHOOD ESTIMATE
TWO SEGMENT, SHAPE PARAMETERS=7.3, 1.9
PERCENT FAILED
99.9
90
80
70
60
50
40
30
20
10
1
10^4
2
3
4
5
6
7
8
9
10^5
LIFE, CYCLES

AFFDL COMPOSITES PROGRAM - AN OVERVIEW

BY

G P SENDECKYJ
STRUCTURAL INTEGRITY BRANCH
STRUCTURAL MECHANICS DIVISION
AIR FORCE FLIGHT DYNAMICS LABORATORY

MECHANICS OF COMPOSITE MATERIALS 6.1 PROGRMS	DATE 28 SEP 78 PREP.BY SENDECKYJ	FY / CY	77 / 77	78 / 78	79 / 79	80 / 80	81 / 81	82 / 82	83 / 83	84	TOTAL
STRUCTURAL INTEGRITY RESEARCH - COMPOSITES (G P SENDECKYJ/56104) 23070101											
SENSITIVITY OF OPTIMIZED STRUCTURES (N KHOT/54893) 23070102											
BIAXIAL TESTING OF COMPOSITES (N BERNSTEIN/54893) 23070103											
SPECTRUM LOAD/ENVIRONMENTAL EFFECTS - COMPOSITES (G SENDECKYJ/56104) 23070106											
HEAT TRANSFER AND THERMAL STRESS IN COMPOSITES (D PAUL/55573) 23070112											
											0

TITLE: RESEARCH IN STRUCTURAL INTEGRITY (IN-HOUSE) JON: 23070101

OBJECTIVE: RESOLVE THEORETICAL QUESTIONS AND DEVELOP DAMAGE TOLERANCE AND DURABILITY ANALYSIS METHODS FOR ADVANCED COMPOSITE AND METALLIC AIRFRAME STRUCTURES.

APPROACH: PERFORM MULTI-FACETED THEORETICAL AND EXPERIMENTAL PROGRAM CONSISTING OF FOUR TASKS.

TASK I: STRENGTH AND DAMAGE TOLERANCE OF COMPOSITES

TASK II: DURABILITY OF COMPOSITES

TASK III: DIELECTRIC ATTENUATION AS DAMAGE AND/OR MOISTURE CONTENT INDICATOR FOR COMPOSITES

TASK IV: EFFECT OF LOAD AND ENVIRONMENT INTERACTION ON FATIGUE CRACK INITIATION AND GROWTH IN METALS

POTENTIAL APPLICATION AREA:

- DESIGN AND ANALYSIS OF COMPOSITE AND METALLIC STRUCTURES
- AIR FORCE ASIP PROGRAM

TASK I: STRENGTH AND DAMAGE TOLERANCE OF COMPOSITES

- OFF-AXIS TENSION TEST FOR SHEAR CHARACTERIZATION OF COMPOSITES
- CRACK ARRESTMENT CONCEPTS
- NONLINEAR, PROGRESSIVE FAILURE ANALYSIS OF COMPOSITES
- SIZE/VOLUME EFFECTS IN COMPOSITES
- PANEL-TO-PANEL (FABRICATION) VARIABILITY IN COMPOSITES

TASK II: DURABILITY OF COMPOSITES

- IMPROVED TAB DESIGN FOR FATIGUE TESTING OF COMPOSITES
- TIME AT LOAD AND LOADING CYCLE SHAPE EFFECTS ON FATIGUE OF COMPOSITES
- SPECTRUM EFFECTS IN COMPOSITES
- STABILIZATION FIXTURE DESIGN FOR TENSION-COMPRESSION FATIGUE OF COMPOSITES
- STATISTICAL DATA ANALYSIS METHODS
- DAMAGE ACCUMULATION/DOCUMENTATION IN COMPOSITES

TASK III: DIELECTRIC ATTENUATION AS DAMAGE AND/OR MOISTURE CONTENT INDICATOR /OR COMPOSITES

- PRELIMINARY IN-HOUSE EFFORT
- LDF

TITLE: SENSITIVITY OF OPTIMIZED STRUCTURES — JON: 23070102

OBJECTIVE: ASSESS THE PROBLEM OF IMPERFECTION SENSITIVITY CREATED BY OPTIMIZATION OF STRUCTURAL COMPONENTS WHICH ARE CRITICAL IN BUCKLING.

APPROACH: DEVELOP A THEORY TO INVESTIGATE THIS PHENOMENA. SELECT DIFFERENT COMPONENT GEOMETRIES AND MATERIAL MIXTURES AND STUDY THEIR BEHAVIOR.

POTENTIAL APPLICATION AREA:
- AIRFRAME STRUCTURAL PANELS: METALLIC/COMPOSITE
- DAMAGED WING PANELS
- MINIMUM WEIGHT PANEL DESIGN
- DESIGN OF ORTHOTROPIC STIFFENED PANELS

TITLE: BIAXIAL TESTING OF COMPOSITES — JON: 23070103

OBJECTIVE: DESIGN AND FABRICATE A BIAXIAL TEST SYSTEM FOR LAYERED COMPOSITE SYSTEMS

APPROACH: DESIGN A LOAD FRAME AND CONSTRAINT FREE GRIPPING SYSTEM TO APPLY TENSION, COMPRESSION, AND TORSION COUPLED WITH INTERNAL AND EXTERNAL PRESSURE.

POTENTIAL APPLICATION AREA: CONFIDENCE IN ABILITY TO PREDICT STRUCTURAL BEHAVIOR OF COMPOSITE LAMINATES WILL SUBSTANTIALLY INCREASE THEIR APPLICATION TO PRIMARY AIRFRAME STRUCTURES.

TITLE: ANALYSIS OF DAMAGE EFFECTS IN THE FATIGUE LOADING OF STRUCTURAL COMPOSITES BY MEANS OF REAL-TIME MOIRE' INTERFEROMETRY

OBJECTIVE: DEVELOP METHOD OF TRACKING AND ANALYZING FATIGUE DAMAGE IN COMPOSITE MATERIALS

APPROACH: REAL-TIME MOIRE' INTERFEROMETRY

POTENTIAL APPLICATION AREA: DEVELOP DAMAGE GROWTH PREDICTION METHOD

TITLE: SPECTRUM LOAD/ENVIRONMENT INTERACTION JON: 23070106

OBJECTIVE:
- DEVELOP BASIC UNDERSTANDING OF FATIGUE BEHAVIOR
- DEVELOP DURABILITY DESIGN METHODOLOGY
- DEVELOP ACCELERATED TESTING TECHNOLOGY

APPROACH:
- JOINT AFFDL AND LLL PROGRAM
- LLL - GENERATE CREEP RUPTURE DATA
  - GENERATE CONSTANT AMPLITUDE FATIGUE DATA
- AFFDL - GENERATE SPECTRUM LOAD INTERACTION DATA
- BOTH - DEVELOP COMPOSITES FATIGUE THEORY

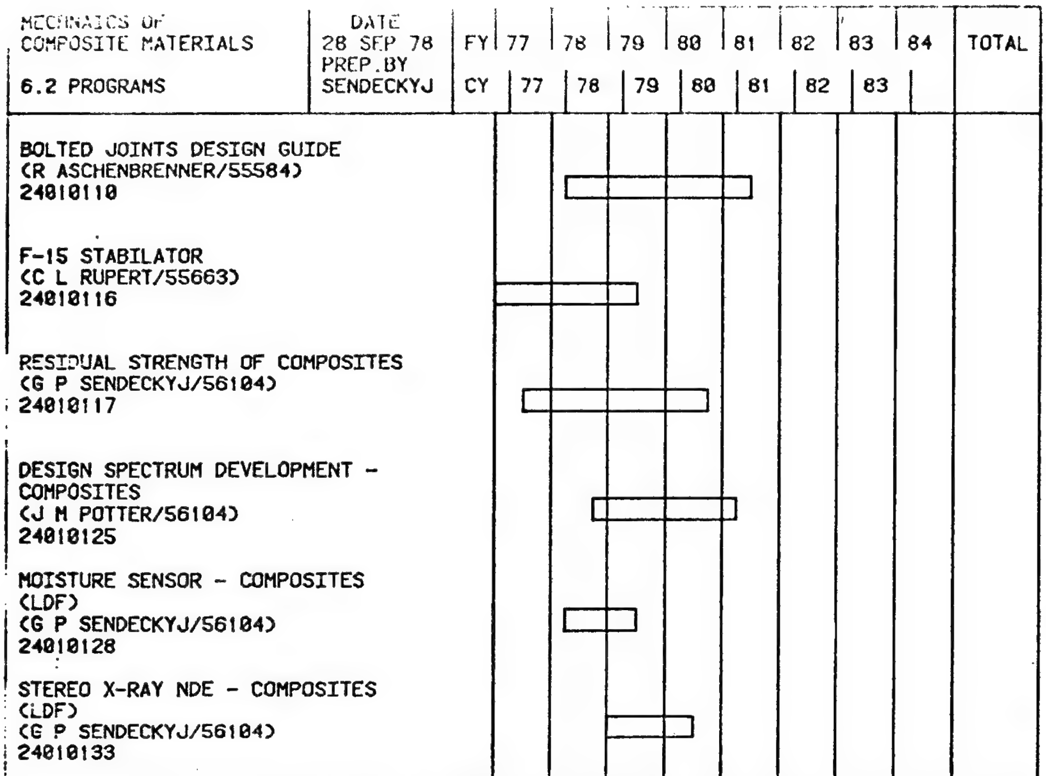
POTENTIAL APPLICATION AREA: AIRCRAFT COMPONENTS MANUFACTURES FROM COMPOSITES

TITLE: HEAT TRANSFER ANALYSIS OF COMPOSITES JON: 23070112

OBJECTIVE: TO PREDICT STRUCTURAL RESPONSE TO RAPID HEATING THREATS SUCH AS LASER WEAPONS

APPROACH:
- PARAMETRIC ANALYSIS VARYING:
  - THERMAL BOUNDARY CONDITIONS (ABSORPTION, CONVECTION, ETC.)
  - TEMPERATURE AND/OR HEAT FLUX DEPENDENT MATERIAL PROPERTIES
- THEORETICAL ANALYSIS AND TESTING TO:
  - VERIFY CURRENT ANALYSIS CONCEPTS
  - IDENTIFY CRITICAL PROPERTIES AND THERMAL BOUNDARY CONDITIONS

POTENTIAL APPLICATION AREA:
- COMPOSITE COMPONENTS OF MISSILES, SPACECRAFT AND AIRCRAFT
- IMPROVED ACCURACY OF SURVIVABILITY STUDIES



EFFECT OF VARIANCES AND MANUFACTURING ANOMALIES ON THE DESIGN STRENGTH AND LIFE OF MECHANICALLY FASTENED COMPOSITE JOINTS

OBJECTIVE: DEVELOP IMPROVED FAILURE CRITERIA AND STRENGTH AND LIFE METHODOLOGIES FOR MECHANICALLY FASTENED ANISOTROPIC COMPOSITE MATERIAL JOINTS

APPROACH : LITERATURE SEARCH
POSTULATE FAILURE MECHANISMS AND COMBINE WITH STRESS ANALYSES TO DEVELOP FAILURE CRITERION.
CONDUCT STATIC STRENGTH TESTS ON GRAPHITE-EPOXY JOINTS TO ASSESS THE EFFECTS OF DESIGN VARIABLES AND MANUFACTURING ANOMALIES.
CONDUCT CONSTANT AMPLITUDE AND RANDOM SPECTRA FATIGUE TESTS.
UTILIZE EXPERIMENTAL RESULTS TO REFINE FAILURE CRITERIA AND STRENGTH AND LIFE PREDICTION METHODOLOGIES.

CONTRACT : FY78 FY79 FY80 FY81 TOTAL

JON: 24010110 **PROJECT ENGINEER:** R.J. ASCHENBRENNER
START DATE: 15 FEB 78 **END DATE:** 15 APR 81

24010116
JON: ~~13670551~~

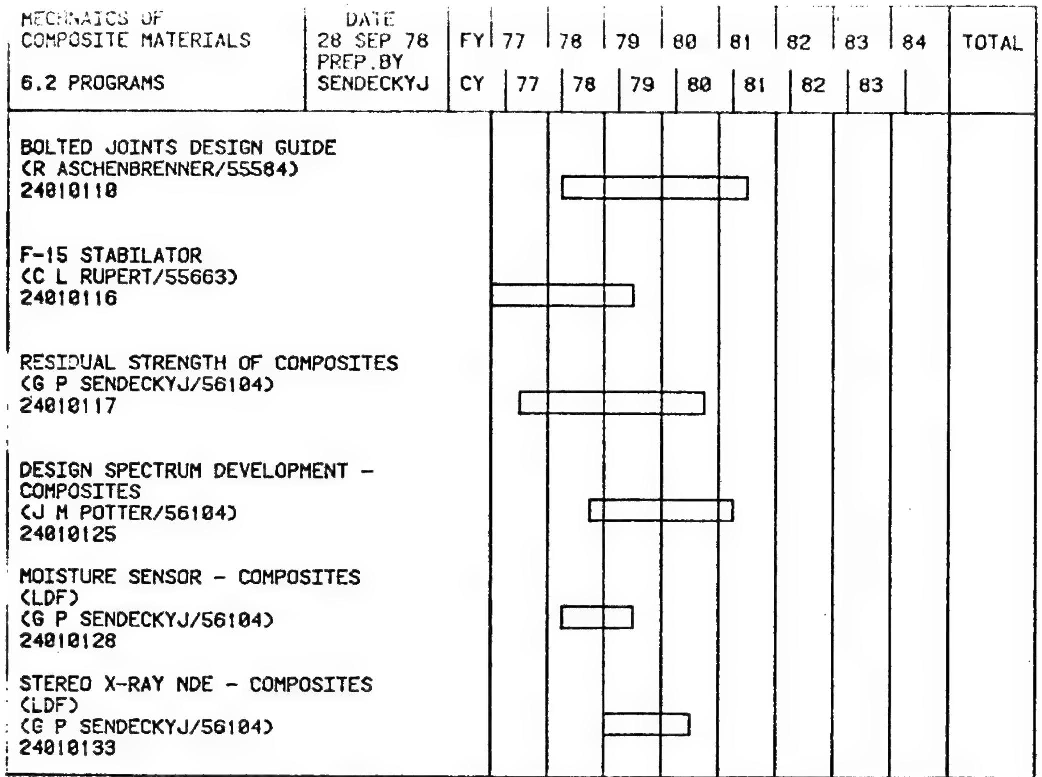
TITLE : EFFECT OF SERVICE ENVIRONMENT ON F-15 BORON-EPOXY STABILATOR

OBJECTIVE: DETERMINE STRUCTURAL DEGRADATION OF COMPOSITE MATERIAL RESULTING FROM MOISTURE ABSORPTION DURING SERVICE OPERATION.

APPROACH : EVALUATE STABILATORS REMOVED FROM AN F-15 AIRCRAFT THAT HAS A HIGH HUMIDITY ENVIRONMENTAL HISTORY

CONTRACT : F33615-77-C-3124 AMOUNT: $[redacted]

START : 25 AUG 77 END : 1 Sep 79



EFFECT OF VARIANCES AND MANUFACTURING ANOMALIES ON THE DESIGN STRENGTH AND LIFE OF MECHANICALLY FASTENED COMPOSITE JOINTS

OBJECTIVE: DEVELOP IMPROVED FAILURE CRITERIA AND STRENGTH AND LIFE METHODOLOGIES FOR MECHANICALLY FASTENED ANISOTROPIC COMPOSITE MATERIAL JOINTS

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CONDUCT CONSTANT AMPLITUDE AND RANDOM SPECTRA FATIGUE TESTS.
UTILIZE EXPERIMENTAL RESULTS TO REFINE FAILURE CRITERIA AND STRENGTH AND LIFE PREDICTION METHODOLOGIES.

CONTRACT : FY78 FY79 FY80 FY81 TOTAL

JON: 24010110 **PROJECT ENGINEER:** R.J. ASCHENBRENNER
START DATE: 15 FEB 78 **END DATE:** 15 APR 81

JON: ~~13670331~~ 24010116

TITLE EFFECT OF SERVICE ENVIRONMENT ON F-15 BORON-EPOXY STABILATOR

OBJECTIVE. DETERMINE STRUCTURAL DEGRADATION OF COMPOSITE MATERIAL RESULTING FROM MOISTURE ABSORPTION DURING SERVICE OPERATION.

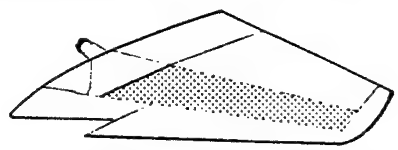
APPROACH EVALUATE STABILATORS REMOVED FROM AN F-15 AIRCRAFT THAT HAS A HIGH HUMIDITY ENVIRONMENTAL HISTORY

CONTRACT F33615-77-C-3124 AMOUNT:

START 25 AUG 77 END : 1 Sep 79

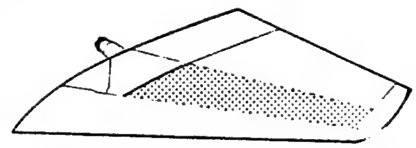
OBJECTIVE: Evaluate Effect of Service Environment on Boron/Epoxy Skins of F-15 Horizontal Stabilator

PRODUCTION F-15 STABILATOR



DOCUMENTED ENVIRONMENTS FROM CLIMATIC TEST PROGRAM

REFURBISHED TEST ARTICLE



FATIGUE AND STATIC TESTS, LONG STORAGE PERIODS

- PREDICT MOISTURE-TIME PROFILES IN BORON/EPOXY LAMINATES ( )
- CONDUCT FULL-SCALE STATIC TESTS OF ONE EAGLE 14 STABILATOR AND PDV-2 STABILATOR
- COMPARE PREDICTED AND MEASURED MOISTURE CONTENTS
- PROJECT LAMINATE STRENGTH DEGRADATION OVER TYPICAL SERVICE LIFE

24010117
~~13670332~~ ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANCED COMPOSITE STRUCTURES

CONTRACTOR: Lockheed-California Company

FUNDING: FY77 FY78 FY79 FY80 TOTAL

START DATE: Dec 76 END DATE: 30 Sep 81

PROBLEM: LACK OF METHODOLOGY FOR PREDICTING RESIDUAL STRENGTH DEGRADATION RATE FOR COMPOSITES

OBJECTIVE: DEVELOP METHODOLOGY FOR PREDICTING THE RESIDUAL STRENGTH AND ITS RATE OF CHANGE AS A FUNCTION OF FATIGUE LOADING FOR ADVANCED COMPOSITE STRUCTURES

APPROACH:
- o GENERATE RESIDUAL STRENGTH DATA AS A FUNCTION OF THE EXTENT OF FATIGUE INDUCED DAMAGE
- o DEVELOP ANALYTICAL METHODOLOGY FOR PREDICTING THE RESIDUAL STRENGTH KNOWING EXTENT OF DAMAGE
- o DEVELOP EMPIRICAL DAMAGE GROWTH LAW

STATUS: Contract Signed 29 Aug 77

24010129 DETERMINATION OF MOISTURE CONTENT IN COMPOSITES BE DIELECTRIC MEASUREMENT

CONTRACTOR: Lockheed-Georgia Co.

OBJECTIVE: QUANTIFY RELATIONSHIP BETWEEN LOCAL MIOSTURE CONTENT AND CAPACITANCE CHANGE MEASURED BY EMBEDDED CAPACITANCE SENSOR
EXPERIMENTALLY DETERMINE THROUGH THICKNESS MOISTURE DISTRIBUTION IN TYPICAL GRAPHITE-EPOXY LAMINATE

APPROACH: FABRICATE MOISTURE ABSORPTION SPECIMENS CONTAINING EMBEDDED CAPACITANCE SENSORS
MOISTURE CONDITION THE SPECIMENS AND MONITOR WEIGTH GAIN AND SENSOR READINGS
CORRELATE AND ANALYZE THE RESULTS

DESIGN SPECTRUM DEVELOPMENT AND GUIDELINES HANDBOOK   JON: 24010125

- OBJECTIVE: TO DEMONSTRATE EXISTENCE OF AND QUANTIFY EFFECTS OF SPECTRUM VARIATIONS ON DURABILITY
- APPROACH: PERFORM ANALYSIS AND TEST LOAD HISTORY VARIATIONS THAT ARE EXPECTED TO HAVE SPECTRUM EFFECTS
- CONTRACTOR: IN NEGOTIATION   AMT:

START DATE: 5 AUG 78 (ESTIMATED)   END DATE: NOV 81

MECHANICS OF COMPOSITE MATERIALS 6.2 PROGRAMS	DATE 28 SEP 78 PREP. BY SENDECKYJ	FY / CY	77 / 77	78 / 78	79 / 79	80 / 80	81 / 81	82 / 82	83 / 83	84	TOTAL
ADVANCED COMPOSITES DESIGN PROGRAM (B L WHITE/55864) 24010301											
COMPOSITE SPECIMEN FABRICATION AND TEST (R ACHARD/56658) 24010314											
PRELIMINARY DESIGN OF ADVANCED WING STRUCTURE (A GONSISKA/55864) 24010320											
ADVANCED COMPOSITES DESIGN GUIDE (A GONSISKA/55864) 24010324											
INTEGRAL COMPOSITE SKIN AND SPAR DESIGN STUDIES (A GONSISKA/55864) 24010328											
STRAIN GAGE ATTACHMENT TO COMPOSITES (J MULLINEAUX/52067) 24010504											

ADVANCED COMPOSITES DESIGN PROGRAM

RESOURCES:

BACKGROUND: UNIVERSITY OF DELAWARE SUBMITTED UNSOLICITED PROPOSAL TO INVESTIGATE PROMISING NEW DESIGNS IN COMPOSITE WING STRUCTURES.

PAYOFF: TO DETERMINE IF THE EMBEDDED SPAR CONCEPT IS A FEASIBLE STRUCTURAL DESIGN.

START DATE: 1 SEP 1977   END DATE: 15 DEC 1978

ADVANCED COMPOSITES DESIGN PROGRAM

JON: 24010301 ENGINEER: B. L. WHITE

CONTRACTOR: UNIVERSITY OF DELAWARE'S CENTER FOR COMPOSITE MATERIALS

OBJECTIVES:

- TO DEVELOP DESIGN INFORMATION FOR ADVANCED STRUCTURAL CONCEPTS
- TO FOSTER ACTIVITIES IN THE UNIVERSITY COMMUNITY IN ADVANCED COMPOSITES DESIGN
- TO CONTRIBUTE TO DEVELOPMENT OF DESIGNERS TRAINED IN ADVANCED COMPOSITES

APPROACH:

- TO INVESTIGATE PROMISING NEW CONCEPTS FOR ATTACHING SPARS TO SKINS IN COMPOSITE WING STRUCTURES

PROGRESS:

- STUDENT ANALYZING AND FABRICATING EMBEDDED SPAR-WING SKIN SECTIONS TO DETERMINE THE EFFECTS OF SPAN LENGTH TO CRITICAL DESIGN LOADS.

WORK UNIT: 24010314

TITLE: COMPOSITE SPECIMEN FABRICATION AND TEST

OBJECTIVES: Experimental Data, Tooling, Q/C, Test Fixtures, Empirical Design Techniques

APPROACH: Flexible Program to Complement Specimen Fabrication and Iterative Design/Fabrication Studies Under Facility Mission

PAY OFF: Composite Airframe Technology, Facility Capability

FUNDING: Oct 76 - Oct 77 20
FY78 30
FY79 40

START DATE: Oct 76

FINAL PRODUCT DATE: Jul 79

PROJECT MONITOR: W. Yarcho

PRINCIPAL INVESTIGATOR: R. Achard

PROGRAM

FBSA Design/Fabrication Studies

FBSC Moisture Absorption/Desorption in Gr/Ep, B/Ep; Effects of Cure Parameters on Composite Properties and Design Requirements

FB Specimen Fabrication FBE
FBR
FBT

FBT Support To Test Programs

Other Support FE
RADC/U. Notre Dame/NASC

PROJECT 24010314

Phase	Description	Project Engineer	Completion Status
I	Tooling Investigation:		
	Angle Fabrication	Beta	30
	Ceramic Tooling	Betă	80
	Heated Ceramic Tooling	Beta	0
	Wing Section Demonstration	Beta	10
II	Process & Test Improvement:		
	Materials Test	Rolfes	50
	Process Studies Phase I	Sandow	80
	Adhesive Tests	Beta	--
	DTA/DSC	--	0
III	Environmental Effects:		
	Moisture Absorption/ Desorption	Shirrell	75
IV	Structural Concepts:		
	T-Specimens	Achard/Rolfes	80

PRELIMINARY DESIGN OF ADVANCED WING STRUCTURE

JON: 24010320 **ENGINEER: A. GONSISKA**

IN-HOUSE EFFORT

OBJECTIVE:
- INVESTIGATE THE LATEST PROMISING DEVELOPMENTS IN THE FIELD OF STRUCTURES TECHNOLOGY
- APPLY THIS NEW TECHNOLOGY IN THE PRELIMINARY DESIGN OF WING STRUCTURES
- SUPPORT AFFDL DESIGN STUDIES

APPROACH:
- CONCENTRATE ON INTEGRAL SKIN/SPAR CONCEPTS
  - DESIGN CONCEPTS
  - CONSTRUCT SPECIMENS
  - TEST SPECIMENS
- REVIEW AND INTERFACE WITH ANY CONTRACTOR EFFORTS IN THIS AREA

PROGRESS:
- ALL TESTING ASSOCIATED WITH PROGRAM HAS BEEN COMPLETED
  - FLATWISE TENSION (DRY AND WET)
  - TRANSVERSE TENSION (DRY AND WET)
- FINAL REPORT HAS BEEN PREPARED FOR TECHNICAL REVIEW COMMITTEE
- PAPER PRESENTED AT THE AIAA MINI-SYMPOSIUM

PRELIMINARY DESIGN OF ADVANCED WING STRUCTURE

BACKGROUND:
- LARGE INTEREST IN INTEGRAL SKIN/SPAR CONCEPTS WITHIN THE AEROSPACE COMMUNITY
- IN-HOUSE EFFORT USED TO INVESTIGATE THE EFFECTS OF VARIOUS DESIGN PROBLEMS ASSOCIATED WITH THIS CONCEPT

PAYOFF:
- STANDARDIZED FLATWISE TENSION TESTING WITHIN INDUSTRY
- TRANSFERRED DESIGN AND TEST DATA
- DEVELOPED EXTENSIVE KNOWLEDGE IN AREAS OF CONSTRUCTION AND TESTING OF CONCEPTS
- ABLE TO EVALUATE CONTRACTORS RESULTS WITH GREATER CONFIDENCE
- CONVINCED INDUSTRY TO INVESTIGATE AREAS OTHER THAN FLATWISE TENSION DRY

START DATE: 23 OCT 73 END DATE: 29 SEP 78

DOD/NASA ADVANCED COMPOSITES DESIGN GUIDE

JON: 24010324 ENGINEER: A. GONSISKA

CONTRACTOR: ROCKWELL INTERNATIONAL

OBJECTIVE: TO PRODUCE A COMPLETELY NEW ADVANCED COMPOSITES DESIGN GUIDE BASED UPON THE THIRD EDITION OF THE AIR FORCE ADVANCED COMPOSITES DESIGN GUIDE.

APPROACH:
- HOLD AN INDUSTRY-GOVERNMENT REVIEW OF CURRENT DESIGN GUIDE
- COLLECT LATEST DATA ON COMPOSITES
- IMPROVE UPON THE FORMAT OF THE CURRENT DESIGN GUIDE

PROGRESS:
- AN INDUSTRY-GOVERNMENT REVIEW OF THE CURRENT DESIGN GUIDE WAS HELD ON 20-21 JUNE 1978
- WORK IS PROCEEDING ON DATA ACQUISITION AND FIRST EDITION DEVELOPMENT

DOD/NASA ADVANCED COMPOSITE DESIGN GUIDE

BACKGROUND:

- CURRENT DESIGN GUIDE IS AN EVOLUTION OF 10 YEARS OF EFFORT
- ADDITIONAL EFFORT NOW REQUIRED DUE TO
  - NEW MATERIALS
  - NEW MANUFACTURING METHODS
  - ENLARGED DATA BASE
- AGREEMENT OF THE DESIGN PANEL OF THE DOD/NASA COMPOSITES INTERDEPENDENCY WORKING GROUP

PAYOFF: DESIGN DOCUMENT OF HIGH UTILITY TO DESIGNERS IN THE AEROSPACE COMMUNITY

INTEGRAL COMPOSITE SKIN AND SPAR DESIGN STUIDES

JON: 24010328 ENGINEER: A. GONSISKA

CONTRACTOR: GRUMMAN AEROSPACE

OBJECTIVE: DEVELOP DESIGN INFORMATION AND ENVIRONMENTAL TEST DATA ON INTEGRAL SKIN/SPAR CONCEPTS

APPROACH:

- THREE CONCEPTS, PLUS A BASELINE, WILL BE SELECTED AND SUBJECTED TO THE FOLLOWING LOADING CONDITIONS.
  - FLATWISE TENSION
  - TRANSVERSE TENSION
  - LONGITUDINAL TENSION
  - LATERAL WEB LOAD
  - SPAR SHEAR
  - IN-PLANE SHEAR
  - COMBINED TRANSVERSE TENSION AND FLATWISE TENSION
  - COMBINED LONGITUDINAL TENSION AND FLATWISE TENSION
  - FATIGUE
  - FLATWISE TENSION AND LATERAL WEB FATIGUE

INTEGRAL COMPOSITE SKIN AND SPAR DESIGN STUDIES

APPROACH (CON'T)

- TESTS WILL BE CONDUCTED AT
  - ROOM TEMPERATURE - DRY
  - 265°F - WET
  - WET FATIGUE WITH THERMAL SPIKES

STATUS: PROCUREMENT ACTIONS HAVE JUST BEEN COMPLETED

PROJECTED RESOURCES:

FY78	FY79	FY80	FY81	TOTAL

START DATE: 11 SEP 78 END DATE: 11 SEP 81

INTEGRAL COMPOSITE SKIN AND SPAR DESIGN STUDIES

BACKGROUND:

- SIMILAR CONCEPTS BEING USED IN THE ADVANCED COMPOSITES ADP CRITICAL COMPONENTS STUDY
- FOLLOW-ON TO THE IN-HOUSE STUDY
- HIGHER RISK THAN "CONVENTIONAL COMPOSITES DESIGN"

PAYOFF:

- POTENTIAL COST SAVINGS
- ELIMINATES STRESS CONCENTRATIONS DUE TO FASTENERS IN LOWER WING SKIN
- IMPROVEMENT IN FUEL SEALANT

TITLE: "STRAIN GAGE ATTACHMENTS TO COMPOSITES" JON: 24010504

OBJECTIVE: DEVELOPMENT OF TECHNIQUES TO ATTACH STRAIN GAGES ON COMPOSITE PARTS WHICH ARE EXPOSED TO HUMIDITY AND ELEVATED TEMPERATURES.

APPROACH: INVESTIGATE NON-EPOXY ADHESIVES AS BONDING AGENTS AND RTV SILICON MATERIAL AS COATINGS FOR STRAIN GAGE INSTALLATION ON COMPOSITE COUPONS.

PAYOFF: RELIABLE STRAIN GAGE DATA WHICH MEASURES PROPERTY CHANGES OF COMPOSITES MATERIALS DUE TO ENVIRONMENTAL CONDITIONS.

START DATE: OCTOBER 1977 **END DATE:** SEPTEMBER 1980

MECHANICS OF COMPOSITE MATERIALS 6.2 PROGRAMS	DATE 28 SEP 78 PREP.BY SENDEKCYJ	FY / CY	77 / 77	78 / 78	79 / 79	80 / 80	81 / 81	82 / 82	83 / 83	84	TOTAL
FATIGUE SENSITIVITY - COMPOSITES (E DEMUTS/53736) 69CW0124											
ENVIRONMETAL SENSITIVITY - COMPOSITES (E DEMUTS/53736) 69CW0128											
SERVICE/MAINTAINABILITY - COMPOSITES (J GARRISON/53736) 69CW0129											
ADVANCED COMPOSITE SERVICEABILITY (R NEFF/53736) 69CW0200											
VALIDATION OF AEROELASTIC TAILORING (M SHIRK/56832) 24010214											
FORWARD SWEPT WING AEROELASTIC STUDIES (M SHIRK/56832) 24010226											

TITLE: FATIGUE SPECTRUM SENSITIVITY OF COMPOSITES JON: 69CW0124

OBJECTIVE: DETERMINE SENSITIVITY OF FATIGUE PROPERTIES TO LOADING AND ENVIRONMENTAL CONTENTS LEADING TO REALISTIC ACCELERATED FATIGUE SPECTRUM SIMULATIONS

APPROACH: EXPERIMENTALLY DETERMINE THE EFFECT OF FREQUENCY, LOAD RATE, LOAD TRUNCATION, AND STRESS LEVEL ON FATIGUE PROPERTIES OF BOLTED AND ADHESIVELY BONDED JOINTS FOR EACH OF THREE ENVIRONMENTS (RTD, RTW, MPTW)

CONTRACTOR: NORTHROP, AIRCRAFT DIVISION **AMT:**

START DATE: JUNE 1975 **END DATE:** SEPTEMBER 1980

PROGRESS

BOLTED JOINTS AT RTD - FREQUENCY AND LOAD RATE TESTS COMPLETE; REAL TIME TESTS 80% COMPLETE

BONDED JOINT TESTING DELAYED BY SEVERAL MONTHS BUT NO IMPACT ON CONTRACT END DATE IS EXPECTED

200K MTS TEST SET UP INVESTIGATION COMPLETED

FABRICATION ON 10 CHANNEL TEST SET UP FOR BONDED JOINTS - IN PROGRESS

ADHESIVE EVALUATION FOR HOT, WET CONDITIONS - IN PROGRESS

BONDED JOINT SPECIMEN REDESIGN - IN PROGRESS

RESULTS

• BOLTED JOINTS @ RTD	ALFA(%)	STRENGTH(%)
LIFETIME (1 VS. 2)	36	2.9
FREQUENCY (.5 VS. 5 HZ).	43	5.0
LOAD RATE (1.2 VS. 12 K/SEC)	6	0.5
LOAD DWELL	-13	-0.4

FIBER VOLUME EFFECT - 10% STRENGTH FOR 1% F.V.

- BONDED JOINTS - LOAD CONTROL

  WAVEFORM CAN AFFECT FATIGUE LIFE BY A FACTOR OF 10

  IDENTICAL WAVEFORMS CAN BE ACHIEVED

  DYNAMIC TRANSIENT LOAD MAY AFFECT GANG TESTING

TITLE: ENVIRONMENTAL SENSITIVITY OF ADVANCED COMPOSITES   JON: 69CW0123

CONTRACTOR: GRUMMAN AEROSPACE   DURATION: 1 SEP 75 - 31 DEC 79

AMOUNT:

BACKGROUND: EFFORTS TO QUALIFY B-1 COMPOSITE STRUCTURES IDENTIFIED A NEED FOR A COST-EFFECTIVE, RELIABLE QUALIFICATION METHODOLOGY FOR COMPOSITE STRUCTURES. THIS EFFORT, IN CONJUNCTION WITH OTHER ROADMAP PROGRAMS, WAS FORMULATED TO PROVIDE DATA NECESSARY TO ESTABLISH THIS QUALIFICATION METHODOLOGY.

OBJECTIVE: ASSESS THE EFFECTS OF REALISTIC ENVIRONMENTAL EXPOSURE ON THE DURABILITY OF ADVANCED COMPOSITES AND ASSESS METHODS FOR SIMULATING THESE EFFECTS IN AN ACCELERATED MANNER IN THE LABORATORY.

ENVIRONMENTAL SENSITIVITY

APPROACH: • DEFINE AVERAGE AND WORST CASE ENVIRONMENTAL EXPOSURE MODELS FOR ALL GENERAL CLASSES OF AF VEHICLES

• CONDUCT A TEST PROGRAM INVOLVING APPROXIMATELY 2000 SPECIMENS TO DETERMINE THE EFFECTS AND INTERACTION OF THE FOLLOWING PARAMETERS ON DURABILITY

- SPECIMENS - THICKNESS AND LAMINATE TYPE
- LOADING - TENSION AND COMPRESSION FATIGUE
- FLIGHT TEMPERATURE - WITH AND WITHOUT
- RUNWAY STORAGE - AVERAGE AND WORST CASE
- TIME -- REAL TIME AND ACCELERATED

PAYOFF: PROVIDE THE DATA NECESSARY TO ESTABLISH ENVIRONMENTAL SIMULATION TECHNIQUES FOR ACCELERATED STRUCTURAL QUALIFICATION TESTING.

PROGRAM PROGRESS

- ENVIRONMENTAL DEFINITION COMPLETED
- ALL SPECIMENS FABRICATED
- TEST RIG FABRICATION COMPLETED
- STATIC TESTS COMPLETED (360 TESTS)
- NOMINAL FATIGUE TESTS NEAR COMPLETION (240 TESTS)
- REAL TIME TESTING INITIATED

TITLE: SERVICE/MAINTAINABILITY OF ADVANCED COMPOSITE STRUCTURES JON: 69CW0129

OBJECTIVE: DEVELOP DESIGN APPROACHES WHICH IMPROVE RESISTANCE OF COMPOSITE STRUCTURES TO GROUND HANDLING DAMAGE.

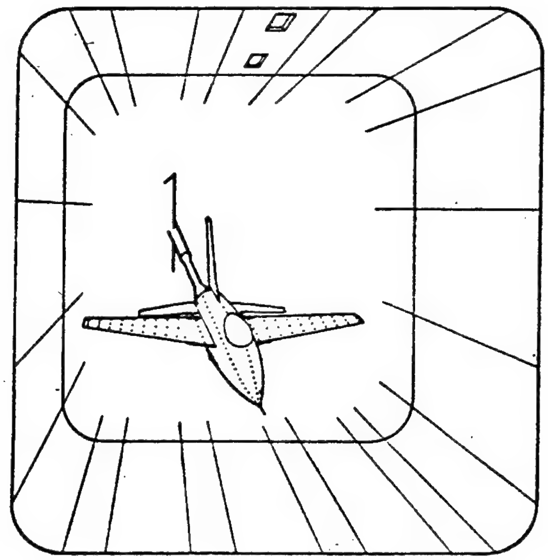
APPROACH: BASED ON SERVICE EXPERIENCE DATA, IMPACT DAMAGE TESTS AND ANALYSIS, DEVELOP IMPROVED DAMAGE RESISTANCE DESIGN APPROACHES AND VALIDATE BY SERVICE SIMULATION TESTS

CONTRACTOR: NORTHROP CORPORATION AMT:

START DATE: 11 NOVEMBER 1976 END DATE: 10 AUGUST 1978

VALIDATION OF AEROELASTIC TAILORING[1]

~~14670326~~
24010214



OBJECTIVE:

- EXPERIMENTALLY VERIFY AERO-ELASTIC TAILORING METHODS

APPROACH:

- DESIGN AND WIND TUNNEL
- TEST AEROELASTICALLY TAILORED MODELS
  - STATIC AEROELASTIC
  - FLUTTER

VERIFY PREDICTIONS OF:

- FORCE AND MOMENT
- PRESSURE
- DEFLECTIO'.
- FLUTTER SPEED

TITLE: FORWARD SWEPT WING AEROELASTIC STUDIES JON: 24010226

OBJECTIVE: ANALYTICALLY AND EXPERIMENTALLY INVESTIGATE DIVERGENCE ELIMINATION IN AEROELASTICALLY TAILORED FORWARD SWEPT WINGS

APPROACH:

- DESIGN AND ANALYSIS OF FSW WIND TUNNEL MODEL
- FABRICATION OF MODEL
- TEST MODEL USING VARIOUS COMPOSITE LAYUPS AT VARIOUS FORWARD SWEEP ANGLES

IN-HOUSE EFFORT

COMPUTER UTILIZATION: $20,000

TOTAL DIRECT MANHOURS: 4400

START DATE: 1 MARCH 1978 END DATE: 30 DECEMBER 1979

AFFDL RESEARCH ACTIVITIES

BY

G P SENDECKYJ
STRUCTURAL INTEGRITY BRANCH
STRUCTURAL MECHANICS DIVISION
AIR FORCE FLIGHT DYNAMICS LABORATORY

IN-HOUSE WORK UNITS

23070101 STRUCTURAL INTEGRITY RESEARCH - COMPOSITES AND METALS
(G P SENDECKYJ)

24010226 FORWARD SWEPT WING AEROLEASTIC STUDIES
(M SHIRK)

24010314 COMPOSITE SPECIMEN FABRICATION AND TEST
(R ACHARD)

24010320 PRELIMINARY DESIGN OF ADVANCED WING STRUCTURE
(A GONSISKA)

24010504 STRAIN GAGE ATTACHMENT TO COMPOSITES
(J MULLINEAUX)

RESEARCH HIGHLIGHTS

DAMAGE DOCUMENTATION IN COMPOSITES - G. P. SENDECKYJ

MOISTURE DIFFUSION STUDIES - CPT C. D. SHIRRELL

PRESENTATIONS/PUBLICATIONS:

"DIFFUSION OF WATER VAPOR IN GRAPHITE/EPOXY COMPOSITES," ASTM CONFERENCE ON ENVIRONMENTAL EFFECTS ON ADVANCED COMPOSITE MATERIALS, DAYTON, SEP 1978

"MOISTURE SORPTION AND DESORPTION IN EPOXY RESIN MATRIX COMPOSITES," 23RD NATIONAL SAMPE SYMPOSIUM, ANAHEIM, 1978

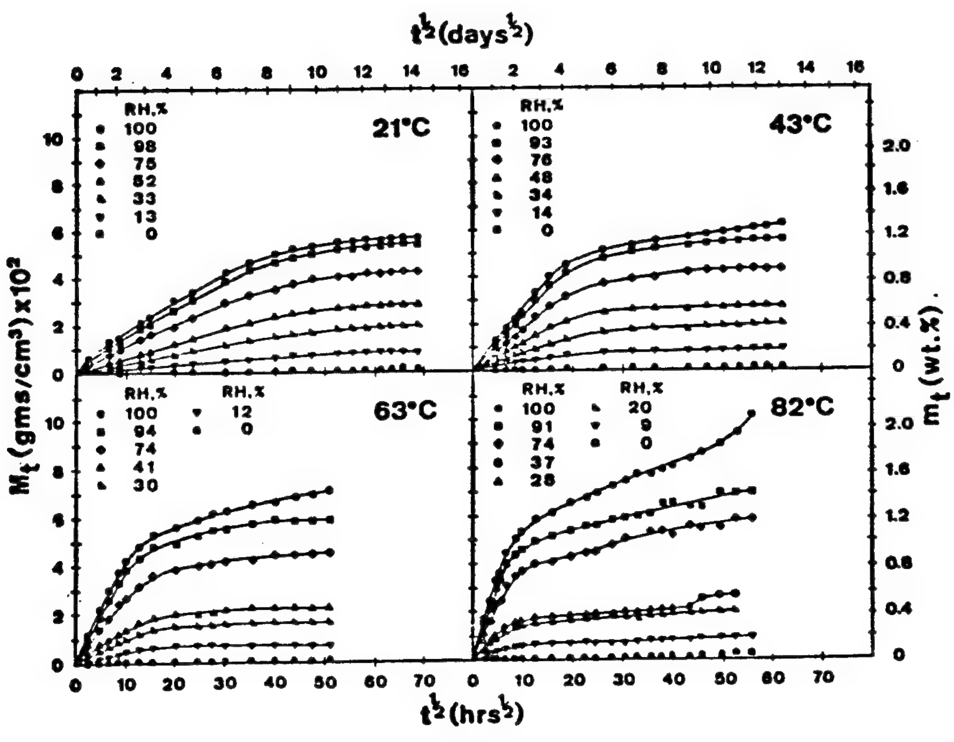
"MOISTURE INDUCED SURFACE DAMAGE IN T300/5208 GRAPHITE-EPOXY LAMINATES", ASTM CONFERENCE ON NDE AND FLAW CRITICALITY FOR COMPOSITE MATERIALS, PHILADELPHIA, OCT 1978

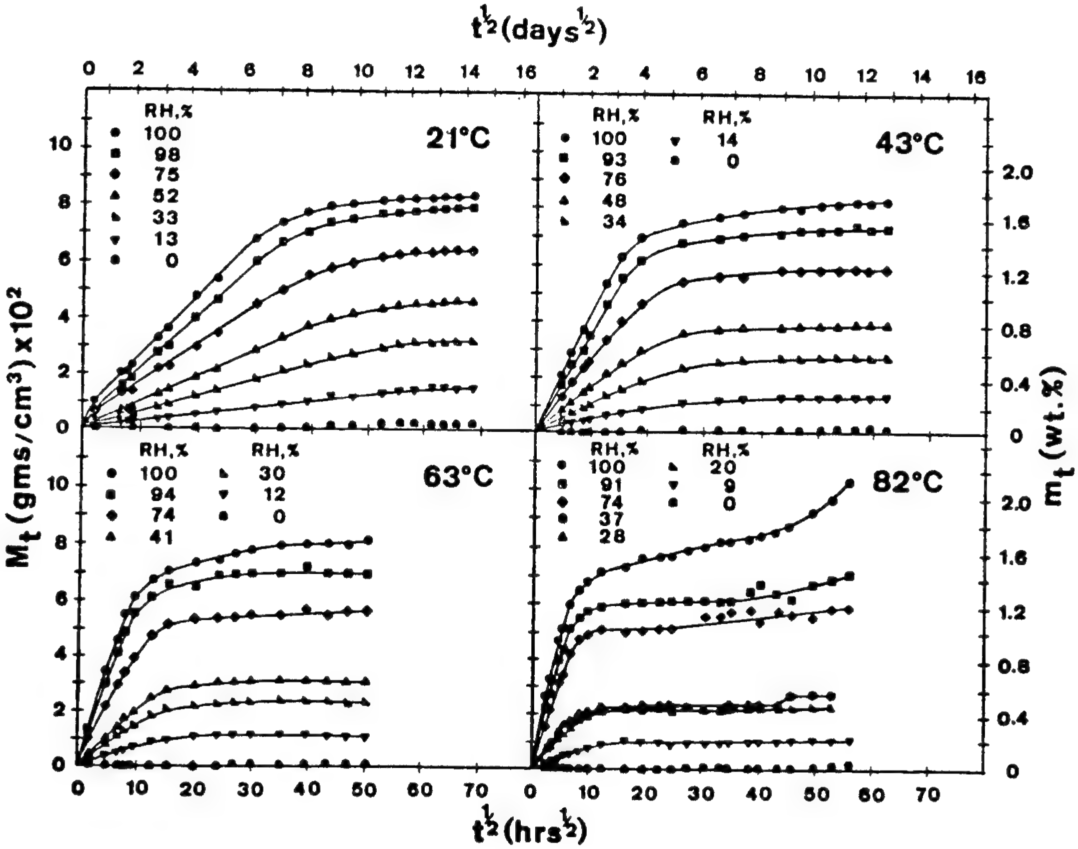
"KINETICS OF MOISTURE DIFFUSION IN THREE ADVANCED COMPOSITE EPOXY-RESIN MATRIX MATERIAL SYSTEMS," 4TH CONFERENCE ON FIBROUS COMPOSITES IN STRUCTURAL DESIGN, SAN DIEGO, NOV 1978

PURPOSE/GOALS OF THIS STUDY

- TO ESTABLISH THE MECHANISM OR MECHANISMS OF MOISTURE SORPTION/DESORPTION IN THE REGIONS OF 0-100% RELATIVE HUMIDITY AND 70°-180°F FOR:
  - T300/5208
  - AS/3501-5
  - BORON/5505

  } EPOXY RESIN MATRIX COMPOSITES
- TO ESTABLISH THE INFLUENCE OF THE FOLLOWING PARAMETERS UPON MOISTURE SORPTION/DESORPTION IN EPOXY RESIN MATRIX COMPOSITES:
  - POSTCURE
  - PLY ORIENTATION/EDGE EFFECTS
  - MOISTURE CONCENTRATION/SWELLING EFFECTS
  - RESIN CONTENT
  - VOID CONTENT
  - ORGANIC COATINGS





$t^{1/2}$(days$^{1/2}$)
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33
13
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21°C
RH,%
100
93
76
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34
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14
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43°C
RH,%
100
94
74
41
RH,%
30
12
0
63°C
RH,%
100
91
74
37
28
RH,%
20
9
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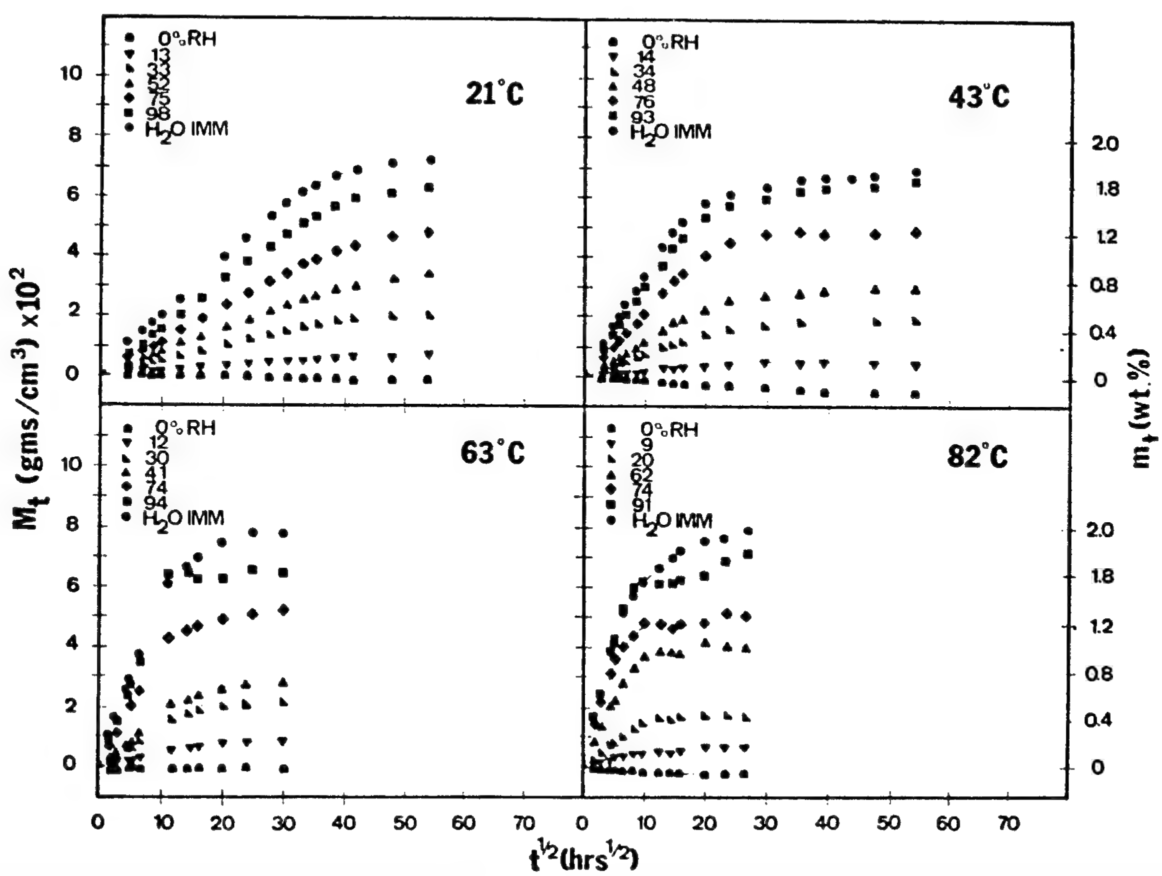
82°C
M_t (gms/cm^3) x10^2
m_t (wt.%)
$t^{1/2}$(hrs$^{1/2}$)



0%RH
13
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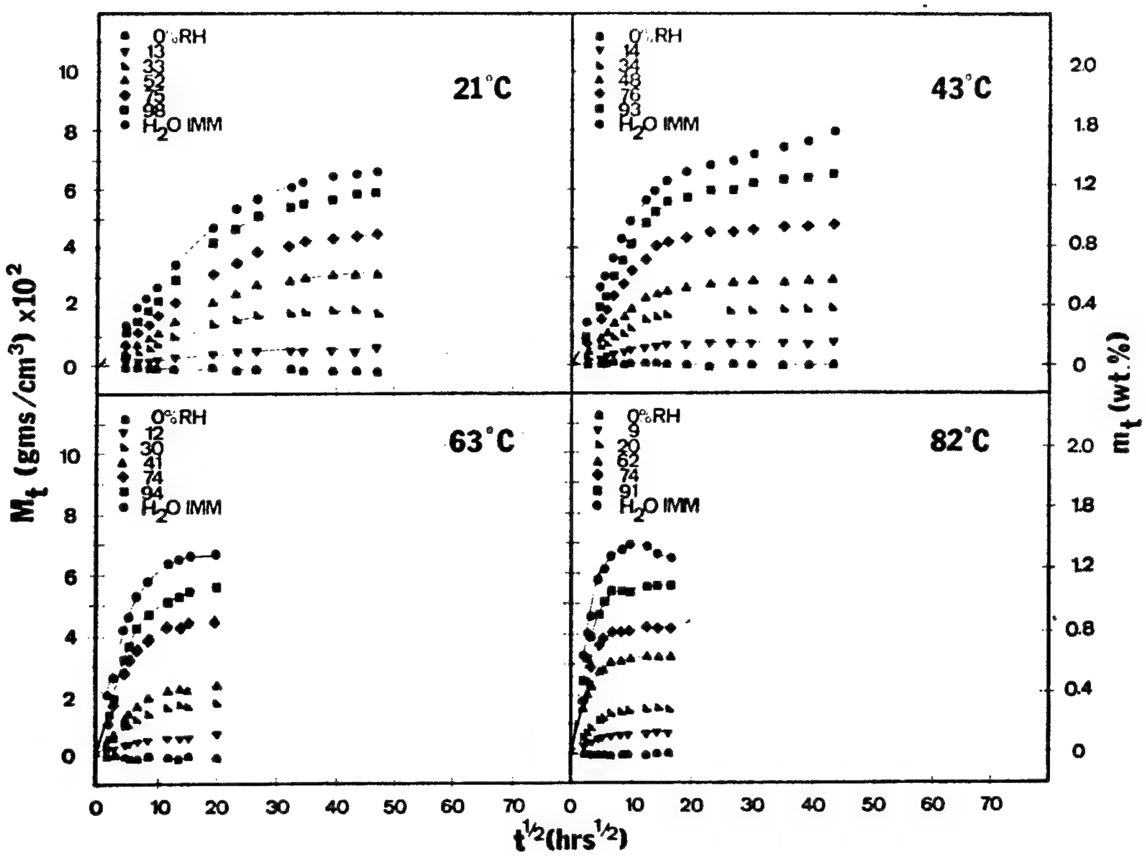
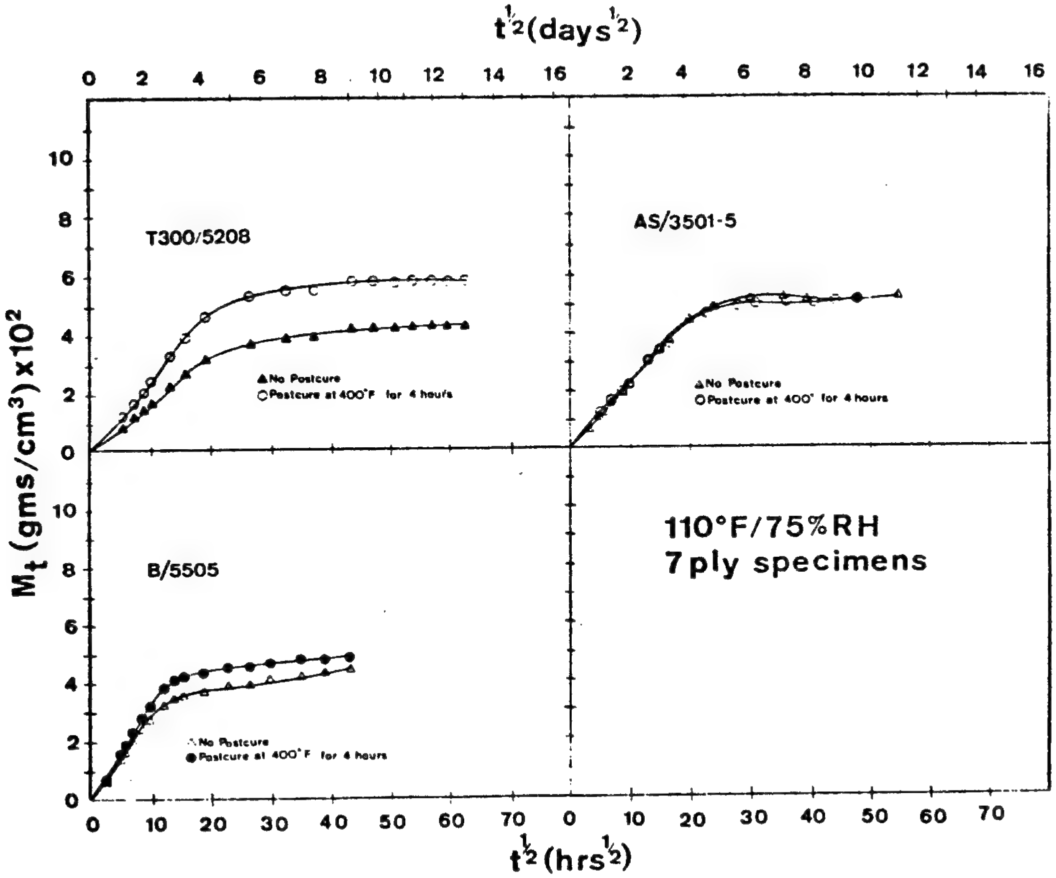
H_2O IMM
82°C
M_t (gms/cm^3) x10^2
m_t (wt.%)
$t^{1/2}$(hrs$^{1/2}$)


21°C
43°C
63°C
82°C
0%RH
H2O IMM
M_t (gms/cm^3) x10^2
m_t (wt.%)
$t^{1/2}$(hrs$^{1/2}$)


$t^{1/2}$(days$^{1/2}$)
T300/5208
AS/3501-5
B/5505
No Postcure
Postcure at 400°F for 4 hours
110°F/75%RH
7ply specimens
M_t (gms/cm^3) x10^2
$t^{1/2}$ (hrs$^{1/2}$)

OBSERVED HYGROTHERMALLY INDUCED DAMAGE
NONPOSTCURED

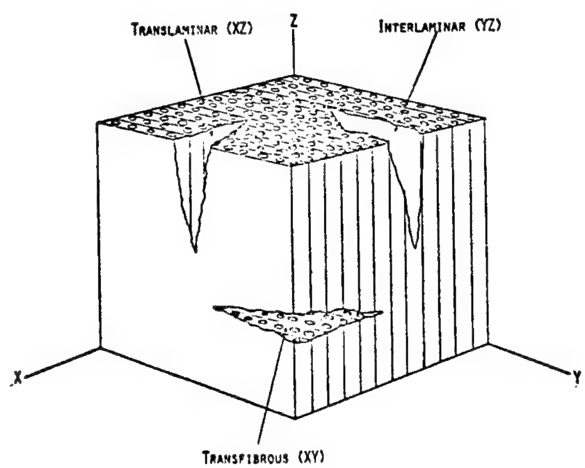
TEMP (°C)	REL. HUM. (%)	DAMAGE	
		SURFACE	EDGE
82	37	VS	S
	75	E	E
	98	E	S
	WATER IMMERSION	S	S

VS -- VERY SLIGHT (1000X); S -- SLIGHT (500X); E -- EXTENSIVE (200X); AND, VE -- VERY EXTENSIVE (100X)

OBSERVED HYGROTHERMALLY INDUCED DAMAGE
POSTCURED

TEMP (°C)	REL. HUM. (%)	DAMAGE	
		SURFACE	EDGE
21	WATER IMMERSION	---	VS
43	WATER IMMERSION	VS	---
63	WATER IMMERSION	VS	VS
82	9	---	VS
	21	VS	VS
	37	S	S
	75	E	E
	98	VE	E
	WATER IMMERSION	E	E

DEFINITIONS OF CRACKS

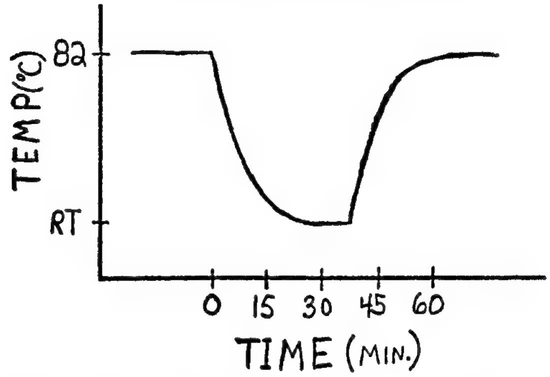


- FROM COOK AND DOWNHILL

HYGROTHERMAL EXPOSURE SEQUENCE

- THE FORMATION OF THE MICROCRACKS CANNOT BE ATTRIBUTED SOLELY TO THE EFFECTS OF ABSORBED MOISTURE. THE EXPERIMENTAL TECHNIQUES USED IN THIS STUDY INFLUENCED THE FORMATION OF THE MICROCRACKS.

TYPICAL WEIGHING SEQUENCE



HYGROTHERMAL EXPOSURE SEQUENCE (cont.)

- THE RAPID COOL-DOWN RATE OF THE SPECIMENS CAUSES THE EXTERIOR TO BE COOLER THAN THE INTERIOR RESULTING IN A THERMALLY INDUCED SURFACE TENSILE STRESS.

- IN ADDITION, THE NONUNIFORM MOISTURE GRADIENT (A RESULT OF SURFACE DESORPTION DURING COOLING) AND THE ACCOMPANIED NONUNIFORM SWELLING WOULD RESULT IN THE FORMATION OF A SURFACE TENSILE STRESS.

- TOGETHER, THESE SURFACE TENSILE STRESSES ARE SUFFICIENTLY LARGE TO CAUSE MICROCRACKING IN THE SURFACES OF THE LAMINATE VIA A CRAZING MECHANISM AT DEFECT SITES ON THE RESIN SURFACE.

CONCLUSIONS

- MICROCRACKS WERE OBSERVED IN THE FACES AND EDGES OF POSTCURED AND NONPOSTCURED T300/5208 LAMINATES EXPOSED AT VARIOUS HYGROTHERMAL CONDITIONS.
  - THE MOST SEVERE MICROCRACKS WERE OBSERVED AT 82°C.
  - THE SEVERITY AND FREQUENCE OF MICROCRACKING INCREASED WITH RELATIVE HUMIDITY.
  - POSTCURED SPECIMENS GENERALLY FORMED MORE SEVERE MICROCRACKS THAN IDENTICALLY EXPOSED NONPOSTCURED SPECIMENS.
  - TRANSLAMINAR MICROCRACKS ON THE FACES OF THE SPECIMENS WERE BOTH MORE FREQUENT AND MORE SEVERE THAN TRANSFIBROUS MICROCRACKS.
  - INTERLAMINAR AND TRANSLAMINAR MICROCRACKS OCCURRED IN THE EDGES OF THE SPECIMENS. HYGROTHERMALLY INDUCED DELAMINATIONS ALSO OCCURRED BETWEEN ADJACENT LAMINAE.
  - THE PRESENCE OF ANISOTROPIC SWELLING STRESSES BETWEEN ADJACENT ORTHOGONALLY ORIENTED LAMINAE WAS INDICATED BY MICROCRACK FORMATION ALONG THE INTERFACE OF THE LAMINAE.

CONCLUSIONS (cont.)

- THE FORMATION OF THESE MICROCRACKS CANNOT BE ATTRIBUTED SOLELY TO THE EFFECTS OF ABSORBED MOISTURE. RATHER, THE EXPERIMENTAL TECHNIQUES USED TO MONITOR THE SPECIMEN WEIGHT GAINS DURING THEIR HYGROTHERMAL EXPOSURES WOULD SUBJECT THE SPECIMENS TO AN INVERTED THERMAL SPIKE WHICH MIGHT INITIATE MICROCRACKING.

- SPECIMENS WITH EXTENSIVE MICROCRACKS ALSO EXHIBITED NONFICKIAN DIFFUSION ANOMALIES DURING THEIR HYGROTHERMAL EXPOSURE.

STRUCTURAL INTEGRITY RESEARCH

PRESENTATIONS/PUBLICATIONS:

"LIFE PREDICTION FOR COMPOSITES," 14TH ANNUAL SES MEETING, LEHIGH U, NOV 1977

"DAMAGE ACCUMULATION IN NOTCHED QUASI-ISOTROPIC GRAPHITE-EPOXY," ASTM COMMITTEE E9 MEETING, ATLANTA, NOV 1977

"IMPROVED LOAD INTRODUCTION TAB DESIGN FOR COMPOSITE MATERIALS TESTING," NEW ORLEANS, MARCH 1978

"COMPARISON OF HOLOGRAPHIC, RADIOGRAPHIC, AND ULTRASONIC TECHNIQUES FOR DAMAGE DETECTION IN COMPOSITE MATERIALS," 2ND INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS, TORONTO, APRIL 1978

"EFFECT OF MOISTURE ON DIELECTRIC PROPERTIES OF RESIN MATRIX COMPOSITES," 23RD NATIONAL SAMPE SYMPOSIUM, 1978

"HOLOGRAPHIC TECHNIQUES FOR DEFECT DETECTION IN COMPOSITE MATERIALS," ASTM CONFERENCE ON NDE AND FLAW CRITICALITY FOR COMPOSITE MATERIALS, PHILADELPHIA, OCT 1978

"EFFECT OF PANEL-TO-PANEL VARIABILITY IN COMPOSITES," 4TH CONFERENCE ON FIBROUS COMPOSITES IN STRUCTURAL DESIGN, SAN DIEGO, NOV 1978

DAMAGE ACCUMULATION STUDIES

OBJECTIVE: DOCUMENT DAMAGE ACCUMULATION PROCESS IN GRAPHITE-EPOXY COMPOSITES
MODEL THE DAMAGE ACCUMULATION PROCESS
IF NECESSARY, DEVELOP EXPERIMENTAL METHODS FOR DOCUMENTING DAMAGE IN COMPOSITES

APPROACH: DOCUMENT DAMAGE ACCUMULATION PROCESS DURING STATIC AND FATIGUE BY USE OF
HOLOGRAPHIC INTERFEROMETRY
TBE ENHANCED X-RAY RADIOGRAPHY
ULTRASONIC NDE METHODS
VARIOUS PENETRANTS

RESULTS: APPLICABILITY OF HOLOGRAPHIC INTERFEROMETRY DEMONSTRATED
ENHANCED STEREO X-RAY RADIOGRAPHY PROGRAM FUNDED BY LDF

DAMAGE DOCUMENTATION METHODS

HOLOGRAPHIC INTERFEROMETRY
- CAN FIND AND DEFINE EXTENT OF DELAMINATIONS AND MATRIX CRACKS IN SURFACE PLIES
- CAN GIVE LIMETED THROUGH THICKNESS INFORMATION

TBE ENHANCED X-RAY RADIOGRAPHY
- CAN FIND MATRIX CRACKS, DELAMINATIONS, AND FIBER BUNDLE FRACTURES
- STANDARD METHOD GIVES NO INFORMATION ON THROUGH THICKNESS DAMAGE DISTRIBUTION
- STEREO RADIOGRAPHY CAN GIVE THROUGH THICKNESS INFORMATION

ULTRASONIC NDE METHODS
- C-SCAN GIVES LIMITED INFORMATION ON DELAMINATIONS
- PULSE-ECHO GIVES INFORMATION ON THROUGH THICKNESS DISTRIBUTION OF DELAMINATIONS

PENETRANTS
- ACCURATE INFORMATION IF USE SECTIONING PROCEDURES

DAMAGE DOCUMENTATION METHODS

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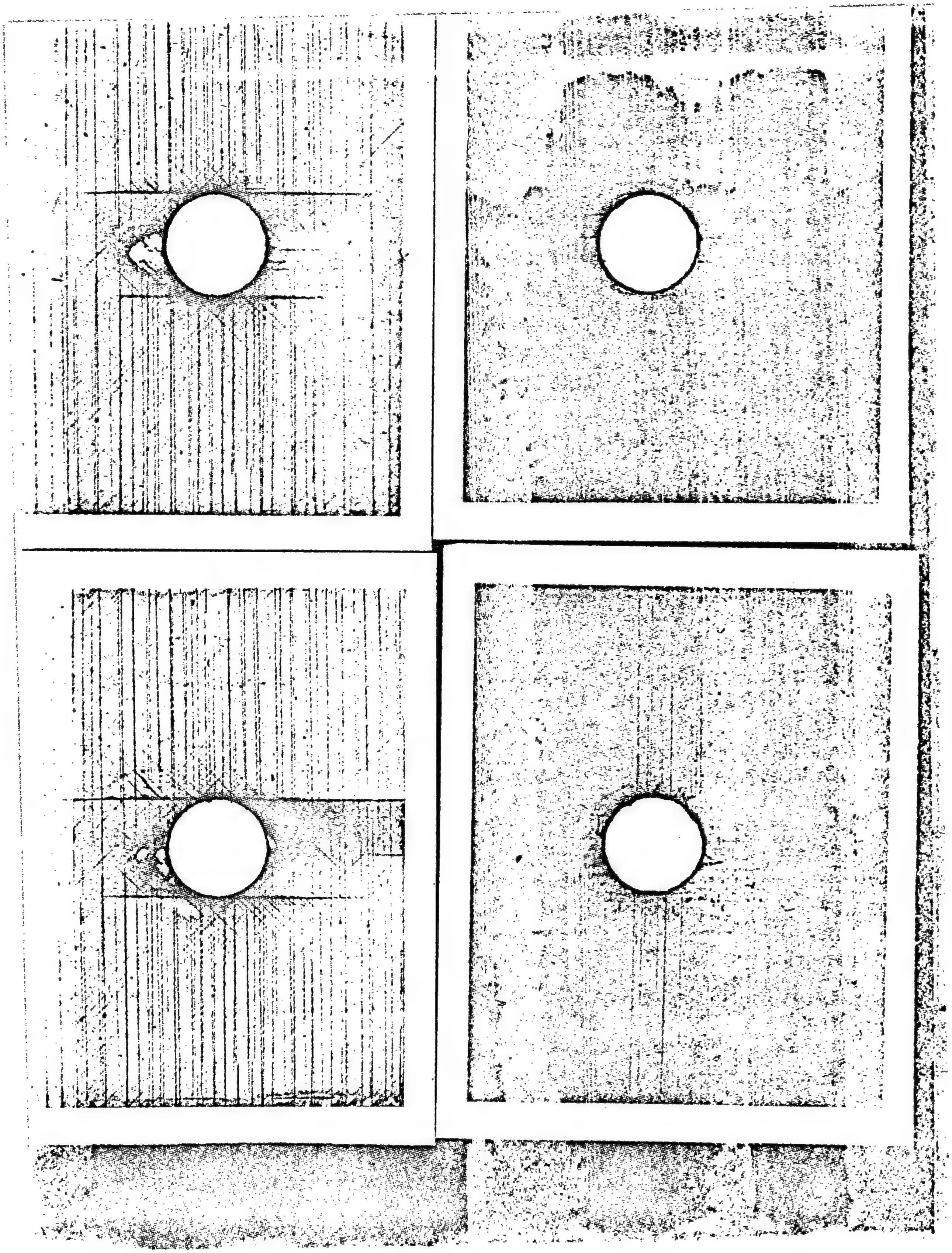
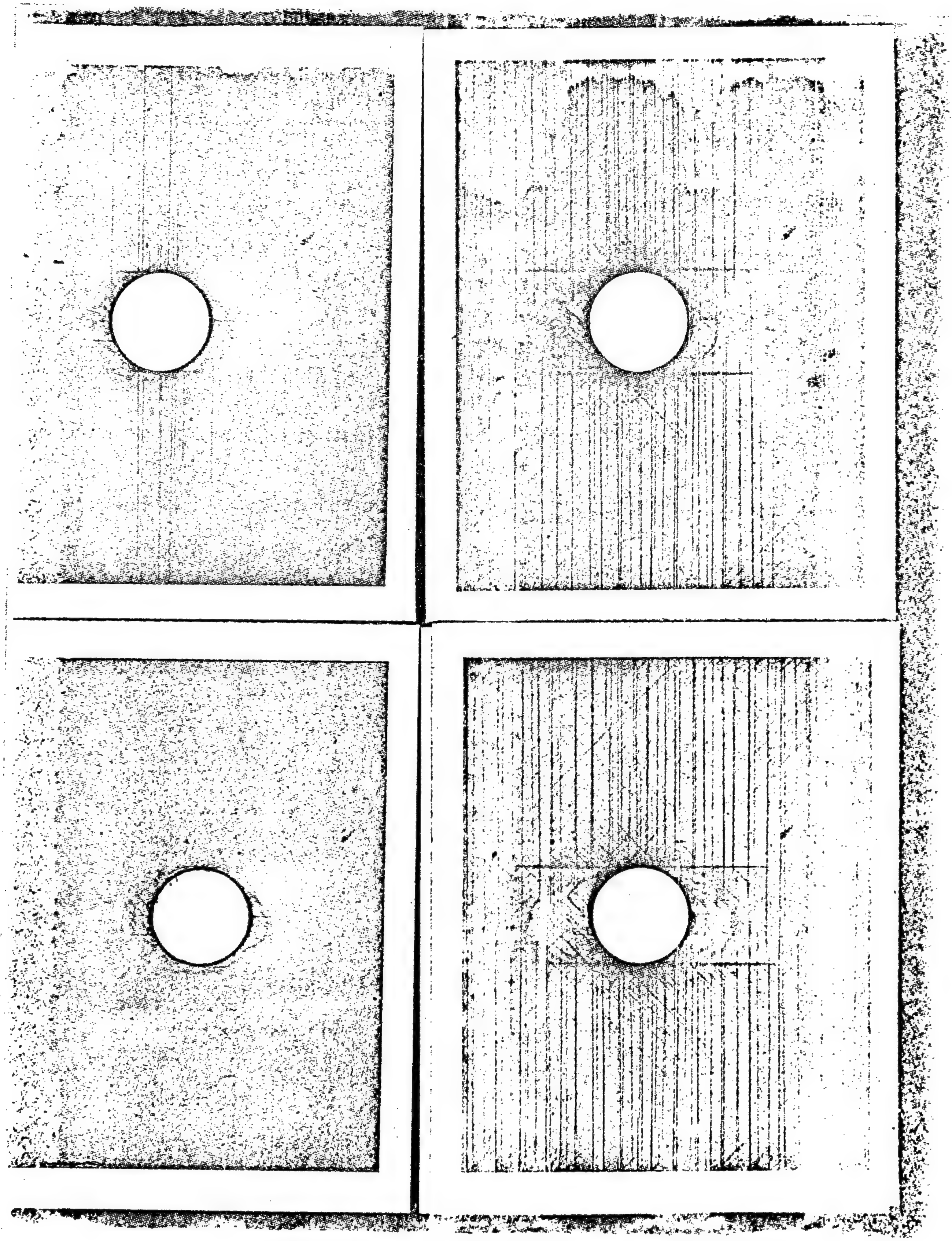
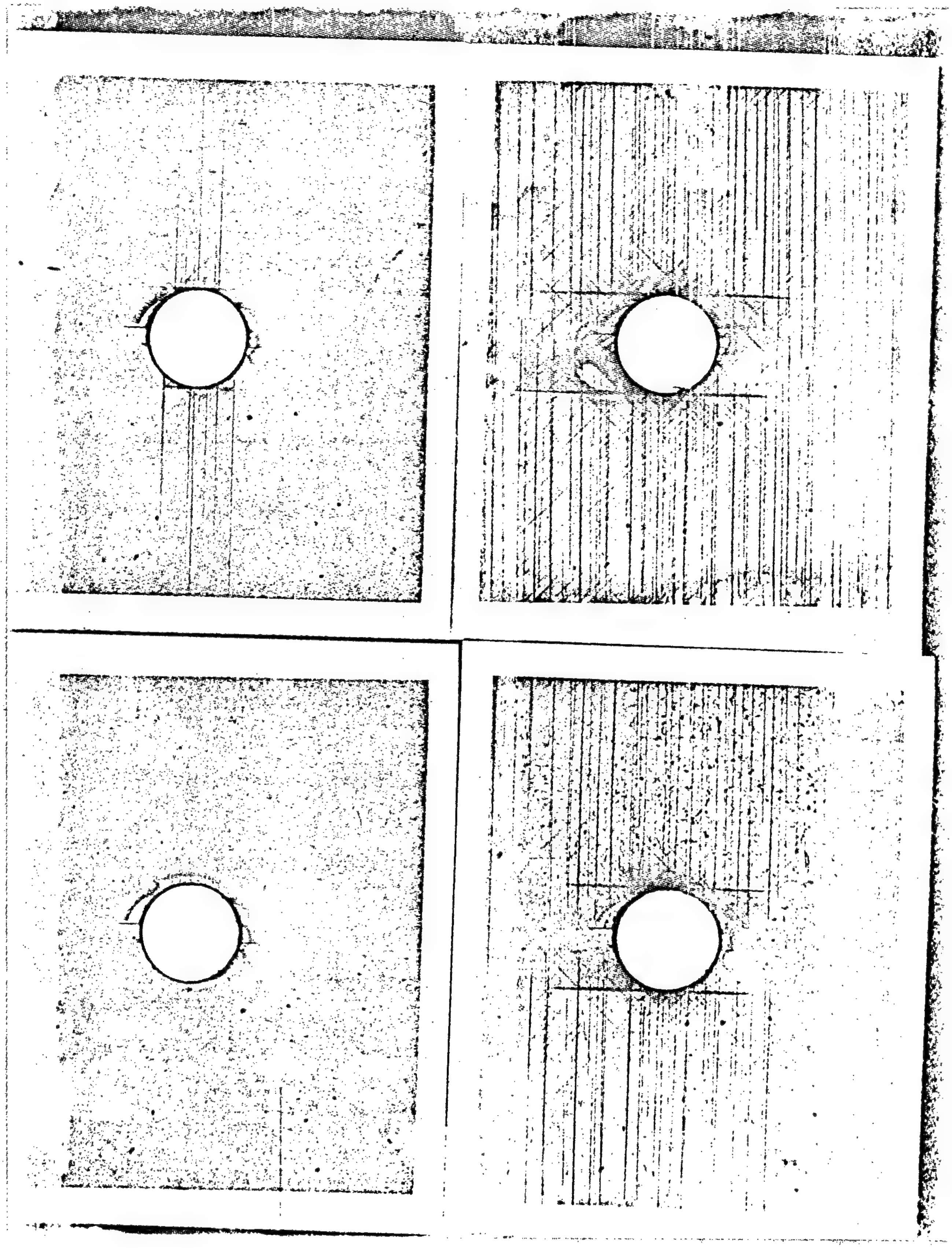
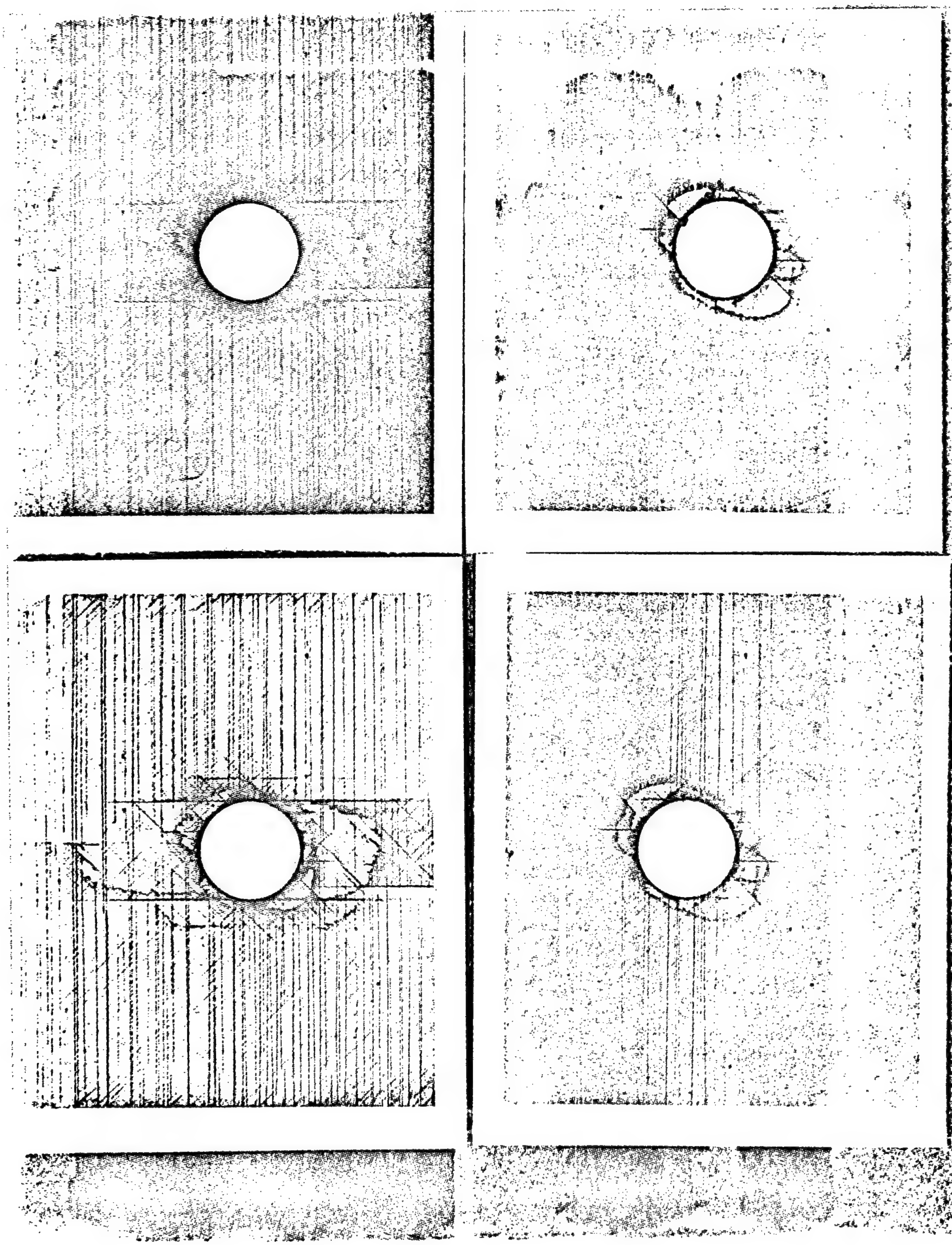
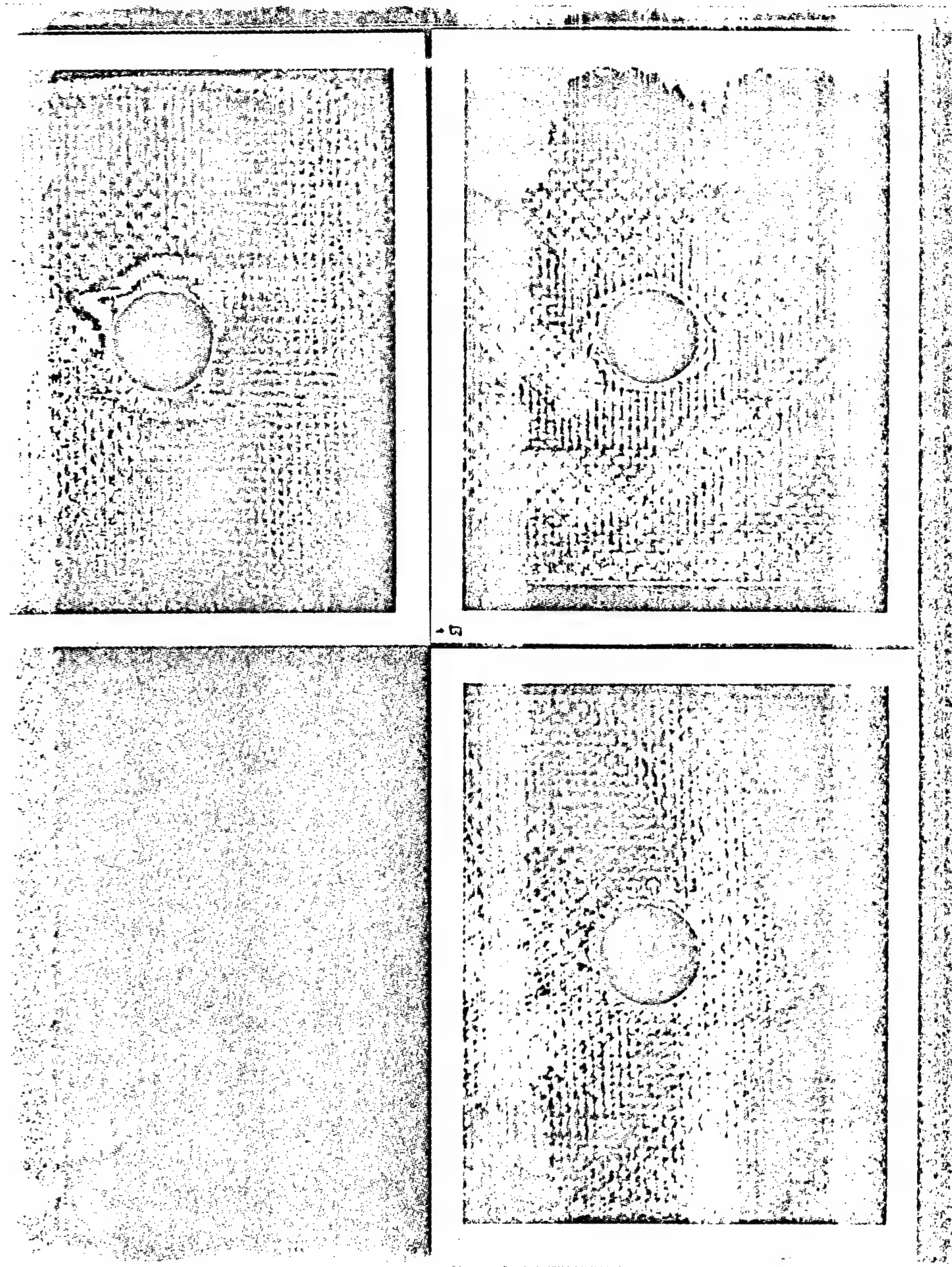
PENETRANTS
- ACCURATE INFORMATION IF USE SECTIONING PROCEDURES

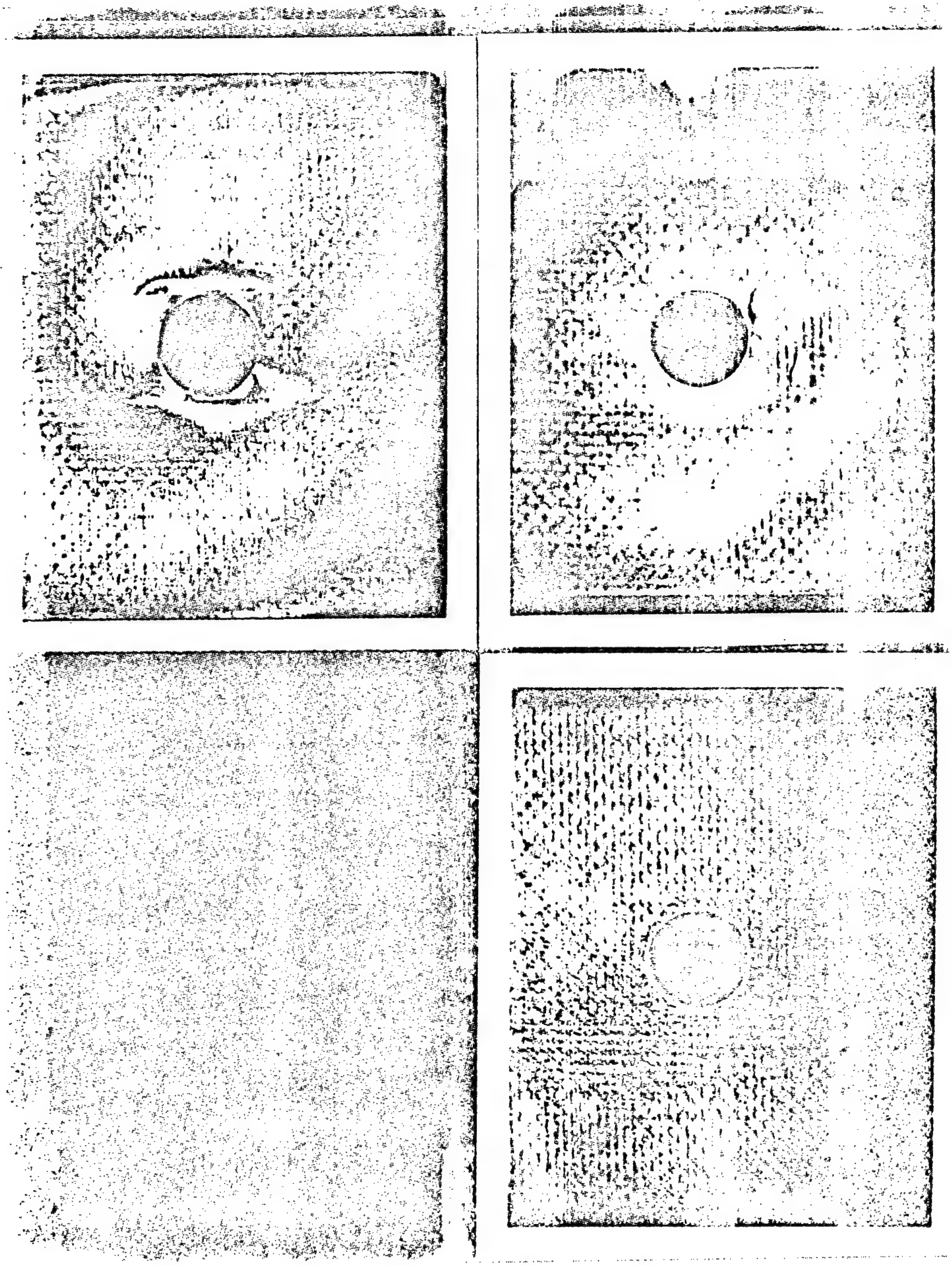


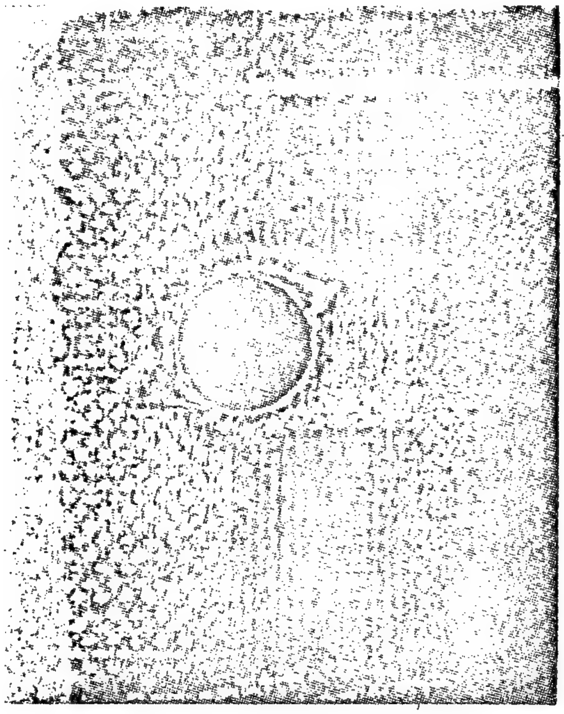


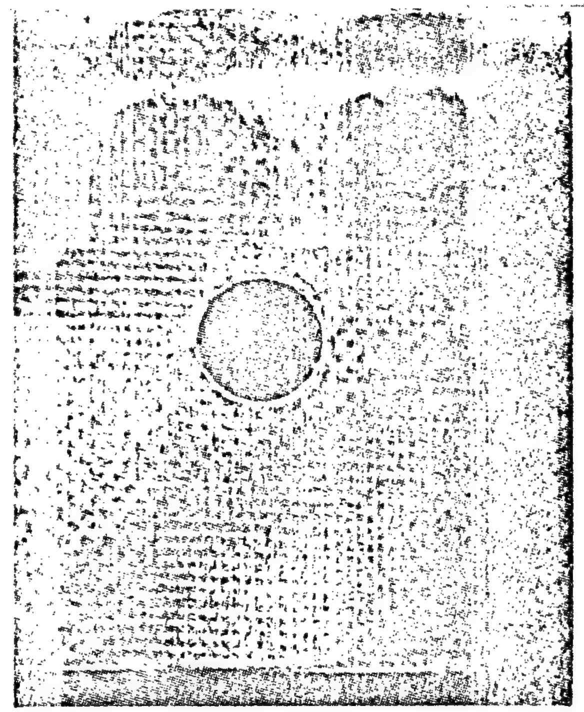












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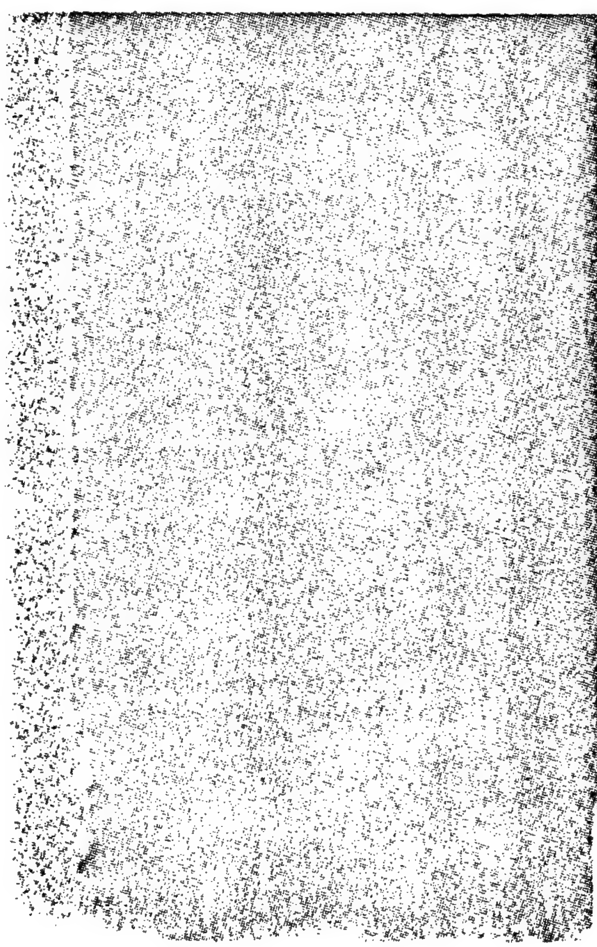

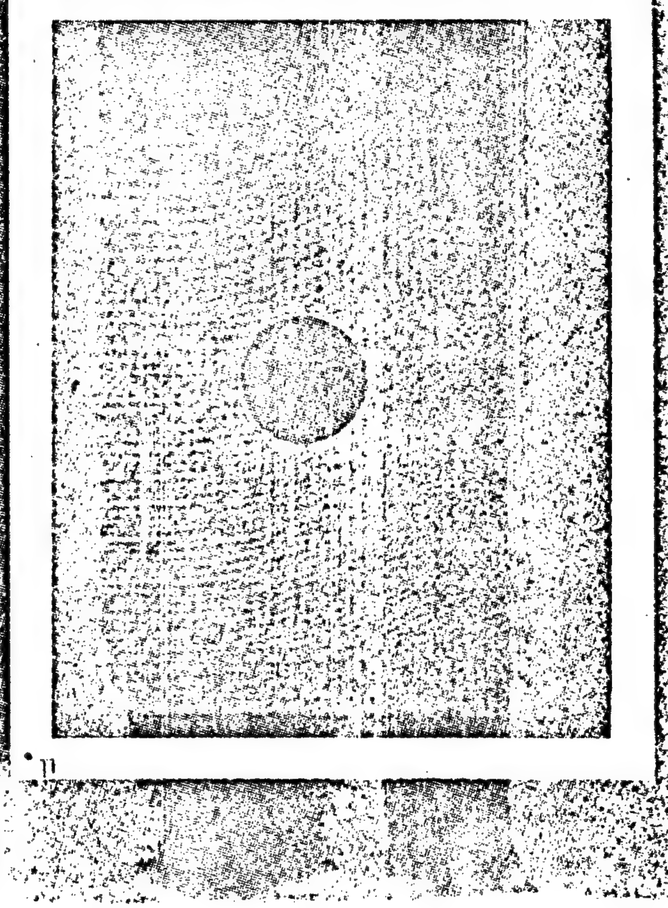

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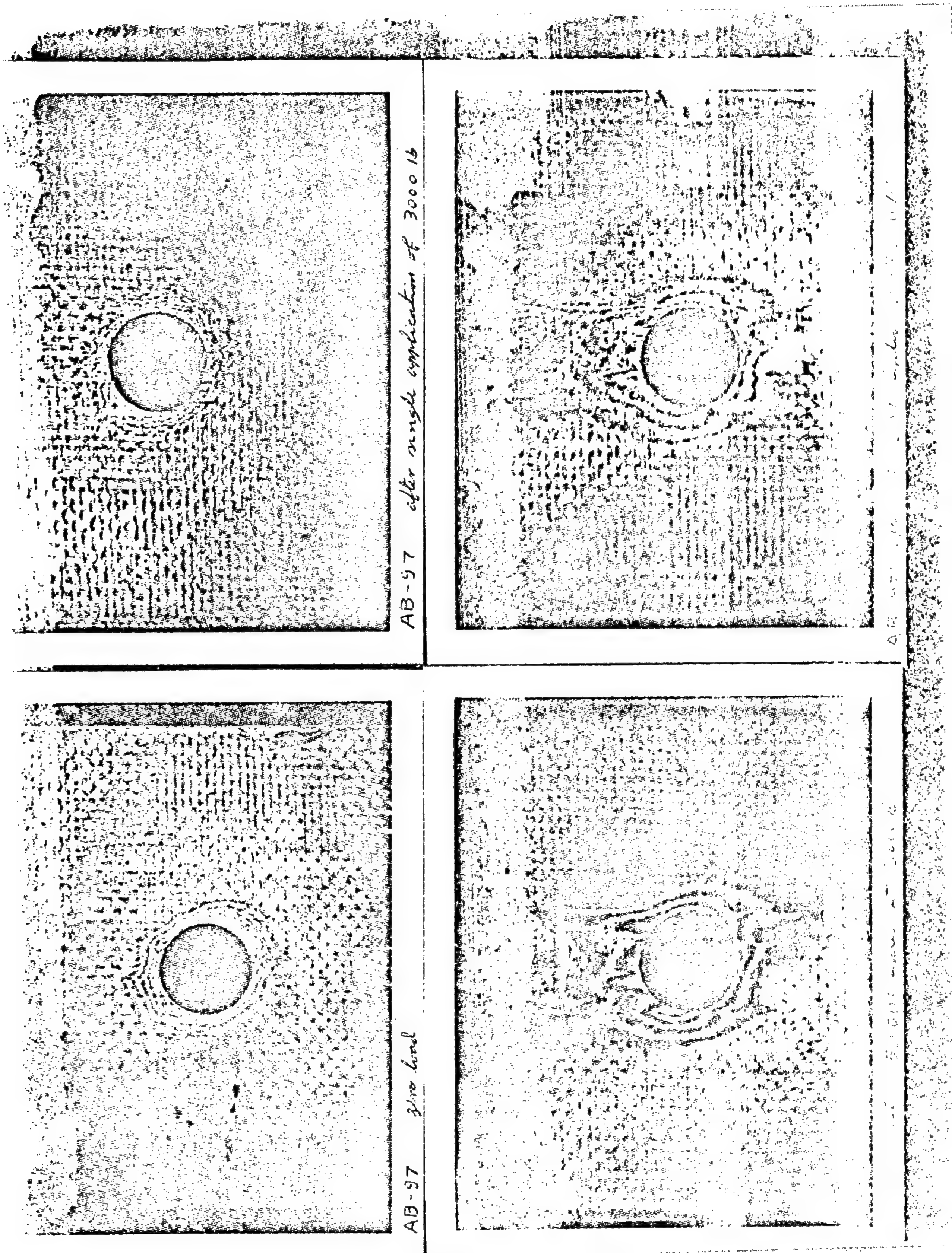
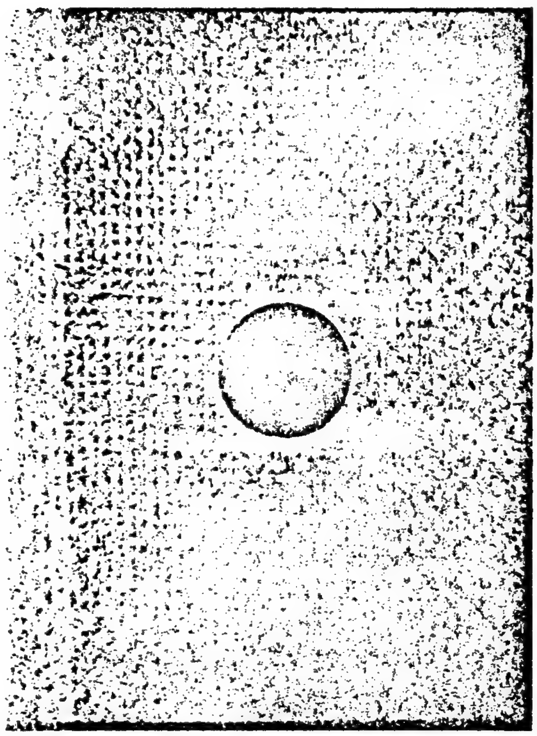
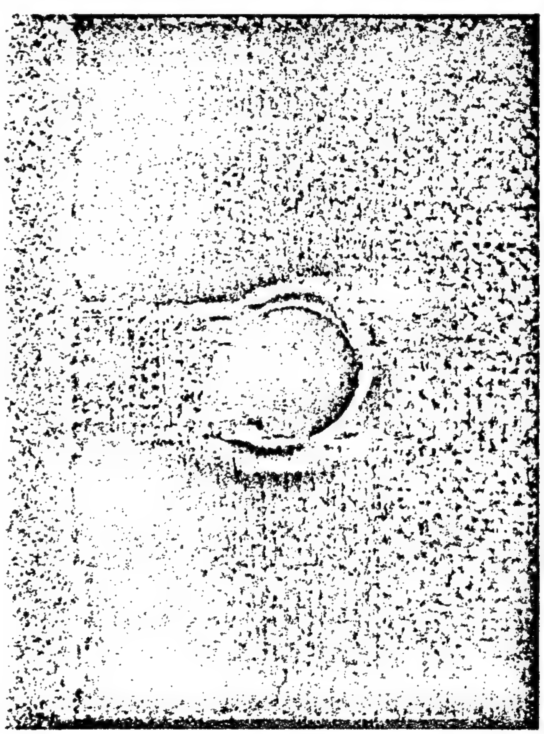

AB-97 after single application of 3000 lb
AB-97 zero load



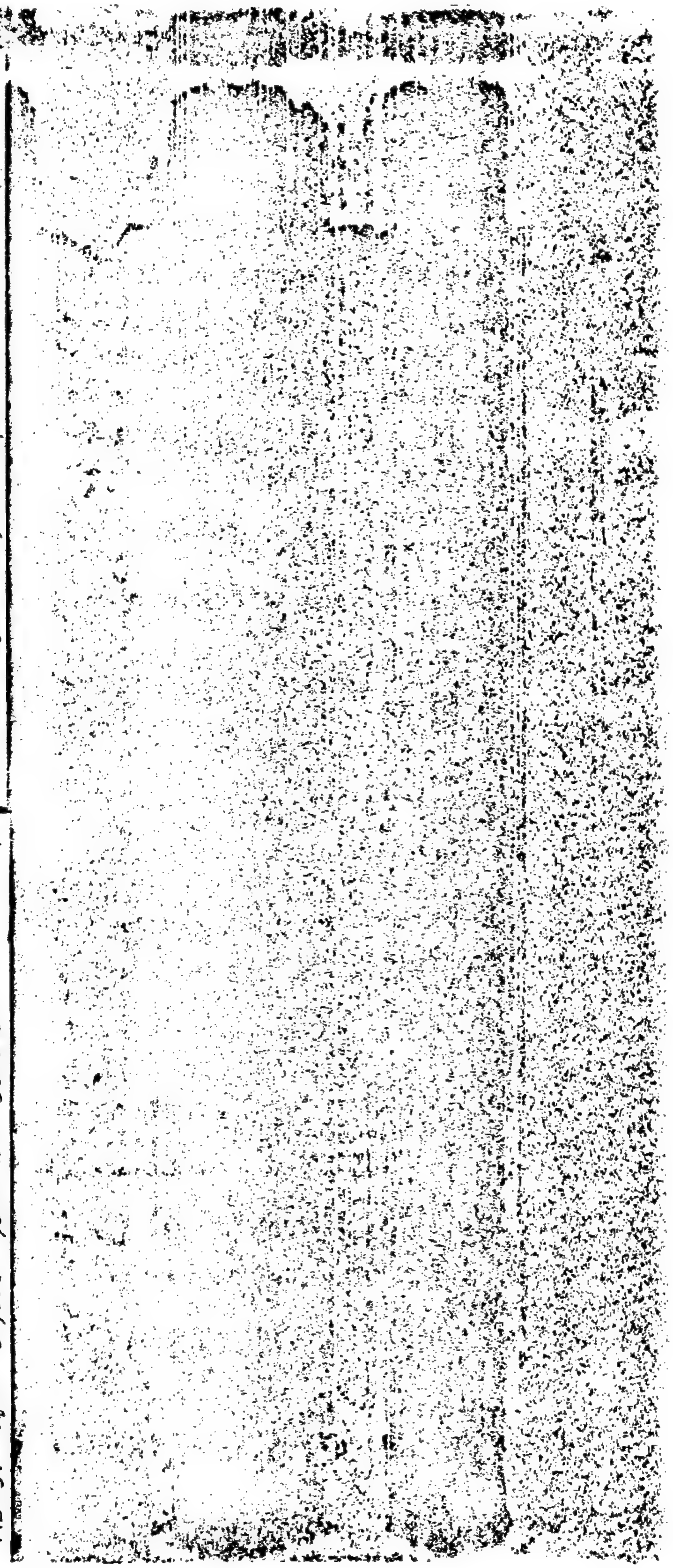
E

AB-97 after 50,001 cycles at 3000 lb



F

AB-97 after 50,001 cycles at 3000 lb



CONTRACT F33615-75-C-5236

FATIGUE SPECTRUM SENSITIVITY STUDY FOR ADVANCED COMPOSITE MATERIALS

PRINCIPAL INVESTIGATOR: L. JEANS

PROJECT ENGINEER: G. GRIMES

AIR FORCE PROJECT MONITOR: DR. E. DEMUTS

NORTHROP

FATIGUE SPECTRUM SENSITIVITY STUDY

OBJECTIVE

- EXPERIMENTALLY DETERMINE SENSITIVITY OF FATIGUE PROPERTIES TO FIGHTER FATIGUE SPECTRA LOADING AND ENVIRONMENTAL CONTENTS

- DEVELOP PROCEDURES AND GUIDELINES FOR DERIVING REALISTIC ACCELERATED/TRUNCATED FATIGUE SPECTRUM SIMULATION

PARAMETRIC TEST MATRIX

			STATIC	BASELINE ▽1		FREQUENCY EFFECTS					TRUNCATION EFFECTS			STRESS LEVEL EFFECTS ▽2			EXTENDED L.T. EFFECTS
RMS				STANDARD		STANDARD					STANDARD			K_1 = STANDARD		K_2 = STD.	STANDARD
TRUNCATION ▽3				9/2		STANDARD (9/2)					7.33/2	10/2	9/1	STD (9/2)		STD. (9/2)	STANDARD (9/2)
FREQUENCY (Hz)				5		0.5	VARIABLE (~5) AVG.		VARIABLE (~0.5) AVG	REAL	5	5	5	5	0.5	5	5
LOAD RATE				VAR.		VAR.	12 K/S	12 K/S DWELL	1.2 K/S	REAL	VAR.	VAR	VAR.	VAR	VAR	VAR	VAR
DURATION (L.T.)				1	2	2	2	2	2	1	2	2	2	2	2	2	UNTIL FATIGUE FAILURE
TASK	ENVIRONMENT																
I	RTD	BONDED T	20	20	40	20	20	20	20	10	20	20	20	20		20	20
		C	20	20	20		20	20		10	20	20	20	20		20	20
		BOLTED T	20	20	40	20	20	20	20	10	20	20	20	20	20	20	10
IIA	LTW	BONDED T	20														
		C	20														
		BOLTED T	20														
	RTW	BONDED T	20	20	20	20		20		10		20	20	20			20
		C	20	20	20			20		10		20	20	20			20
		BOLTED T	20	20	20	20		20		10		20	20	20			10
IIB	MPTW	BONDED T	20 ▽4	20	20	20		20		10		20	20	20			20
		C	20 ▽4	20	20			20		10		20	20	20			20
		BOLTED T	20 ▽4	20	20	20		20		10		20	20	20			10
	TBD	BONDED	30 } MOISTURE/TEMPERATURE CHARACTERIZATION														
		BOLTED	20														
III	TBD	AIRCRAFT USAGE AND SPECIMEN CHARACTERISTICS															

▽1 BASELINE SPECTRUM (SAME FOR ALL TASKS)

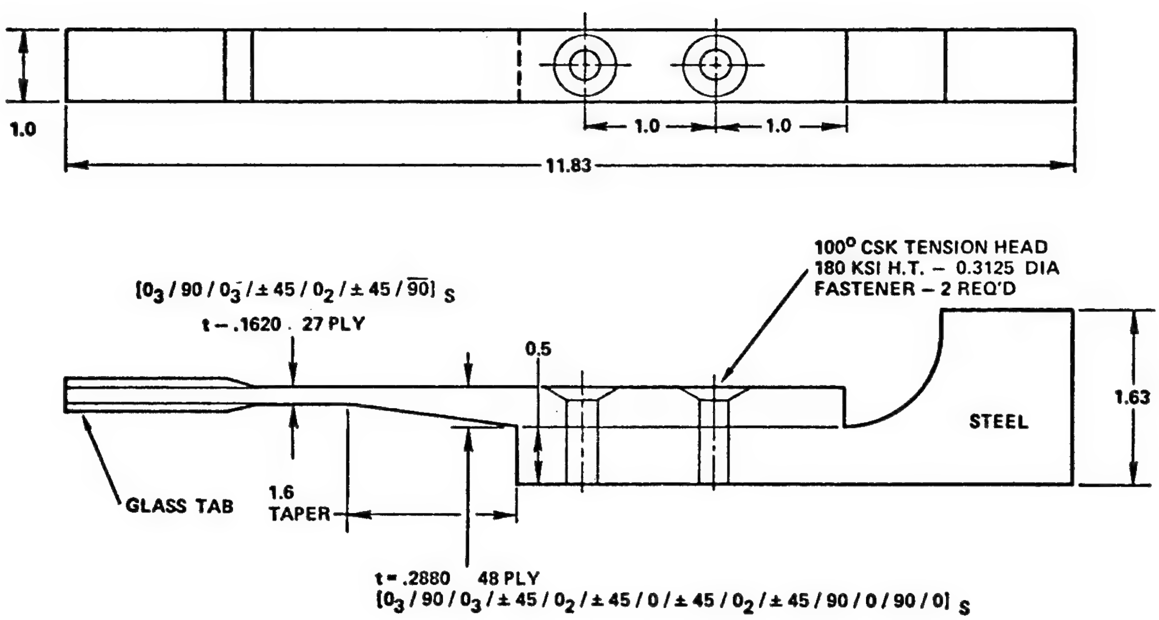
▽2 MULTIPLICATION FACTORS (K_1 AND K_2) TO BE ESTABLISHED.

▽3 NUMBERS SHOWN DENOTE UPPER AND LOWER POSITIVE LOAD FACTOR RANGE (E.G., 9/2 = 9_g UPPER, 2_g LOWER).

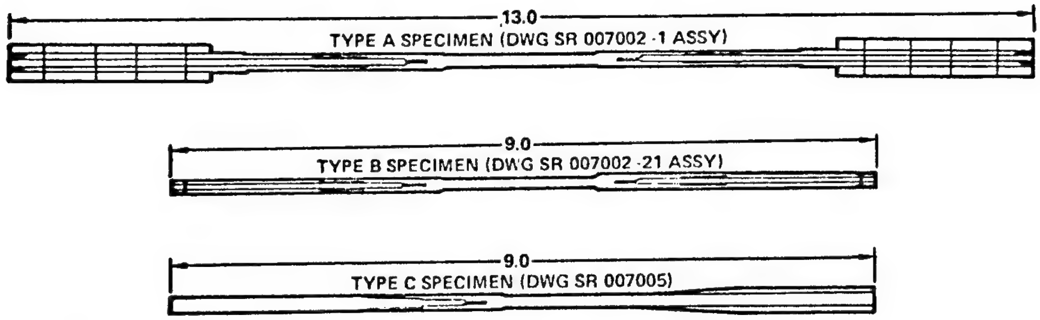
▽4 THESE SPECIMENS TO BE HTW ONLY (NO MISSION PROFILE).

//// INDICATES TESTS COMPLETED OR IN TEST JUNE, '78

BOLTED JOINT SPECIMEN

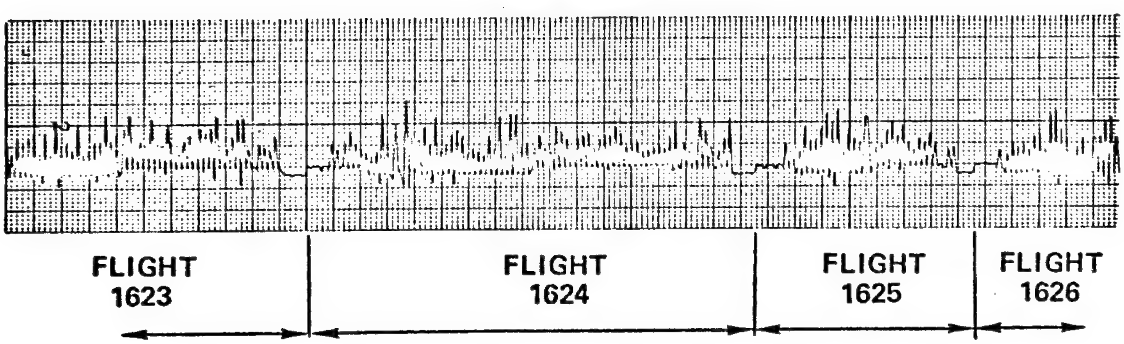


SUMMARY OF BONDED SPECIMEN TYPE AND USAGE

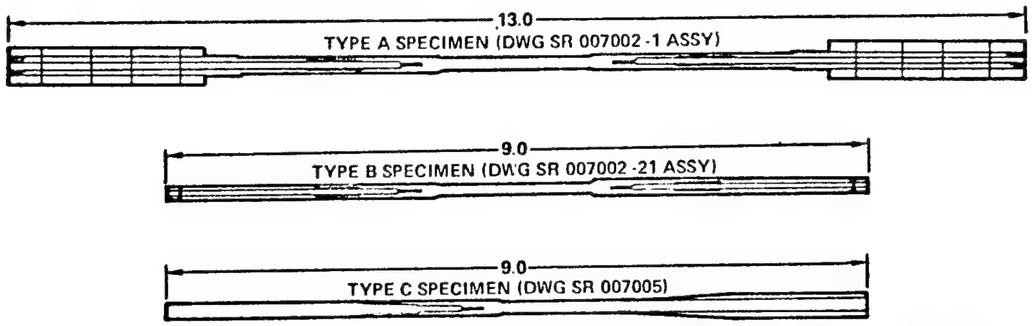


BONDED SPECIMEN TEST SERIES	LOADING TYPE	FREQUENCY	SPECIMEN TYPE	SPECIMEN NO.
1A	TENSION	STATIC TENSION	A	20
1B		STATIC TENSION	B	10
2		STATIC COMP	A	20
3		BASELINE (5 Hz)	B	40
4		BASELINE (5 Hz) (1 LT)	B	20
5		(0.5 Hz)	B	20
6		12 KIPS/SEC	B	20
7		1.2 KIPS/SEC	B	20
8		1.2 KIPS/SEC (DWELL)	B	20
9/13	TEN/COMP	REAL TIME	A	20
10	COMP	5 Hz (COMP)	C	20
11	COMP	5 Hz (COMP)	C	20
			(ETC)	

TYPICAL FIGHTER AIRCRAFT FLIGHT-BY-FLIGHT LOAD TIME HISTORY (CONSTANT FREQUENCY) GENERATED BY DIGITAL TECHNIQUES IN THIS STUDY

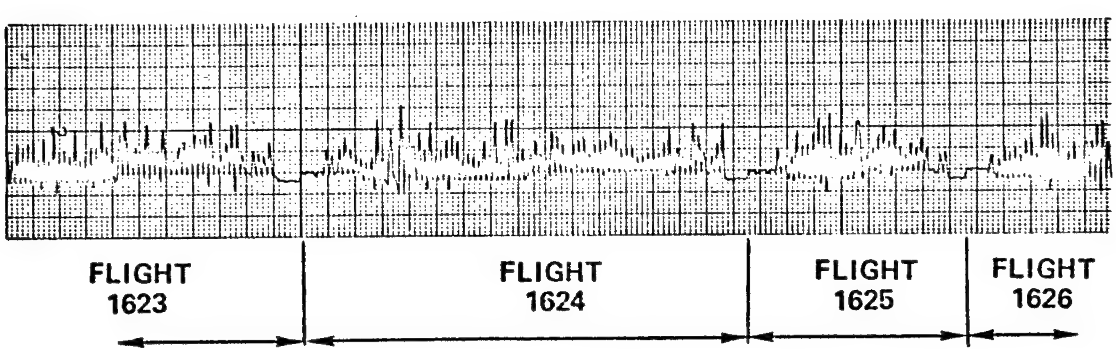


SUMMARY OF BONDED SPECIMEN TYPE AND USAGE

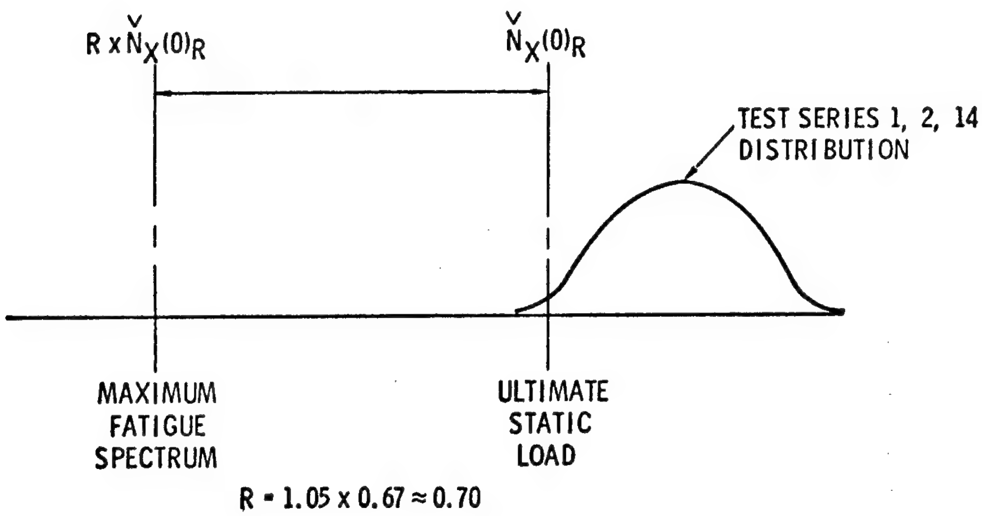


BONDED SPECIMEN TEST SERIES	LOADING TYPE	FREQUENCY	SPECIMEN TYPE	SPECIMEN NO.
1A	TENSION	STATIC TENSION	A	20
1B		STATIC TENSION	B	10
2		STATIC COMP	A	20
3		BASELINE (5 Hz)	B	40
4		BASELINE (5 Hz) (1 LT)	B	20
5		(0.5 Hz)	B	20
6		12 KIPS/SEC	B	20
7		1.2 KIPS/SEC	B	20
8		1.2 KIPS/SEC (DWELL)	B	20
9/13	TEN/COMP	REAL TIME	A	20
10	COMP	5 Hz (COMP)	C	20
11	COMP	5 Hz (COMP)	C	20
			(ETC)	

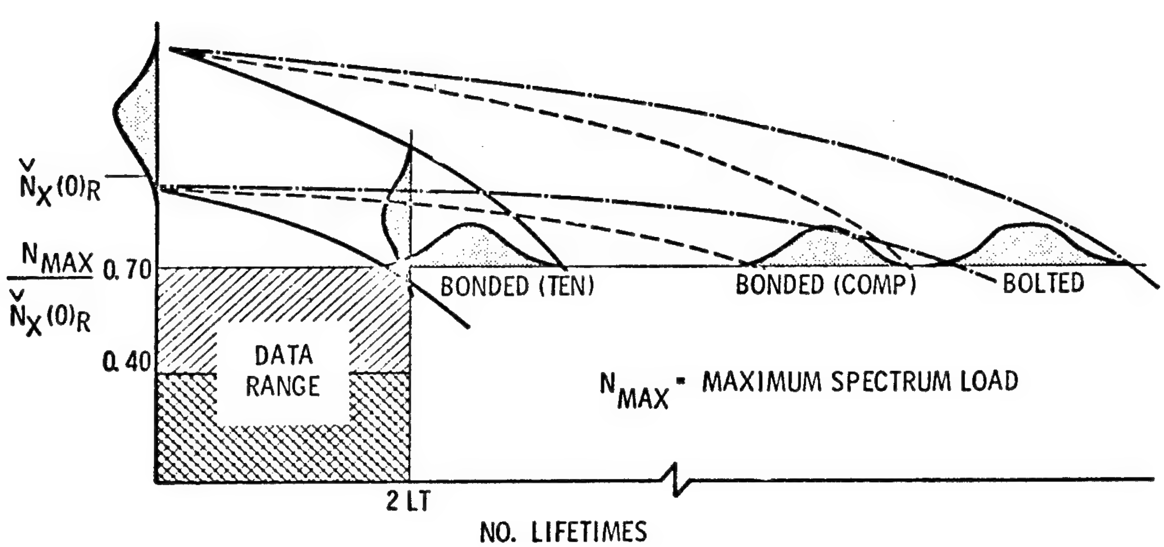
TYPICAL FIGHTER AIRCRAFT FLIGHT-BY-FLIGHT LOAD TIME HISTORY (CONSTANT FREQUENCY) GENERATED BY DIGITAL TECHNIQUES IN THIS STUDY



FATIGUE "OPERATING STRESS" CRITERIA

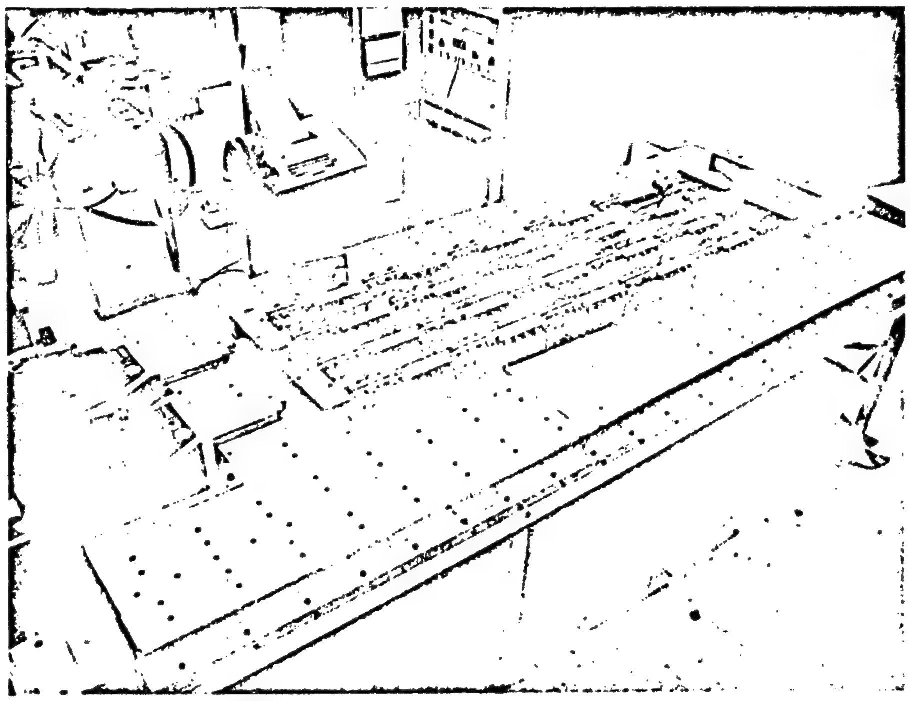


SPECTRUM SEVERITY PHILOSOPHY (CONT'D)



MULTI-STATION DURABILITY TEST UNIT (MSDTU)

REAL TIME RTD AND RTW BONDED SPECIMEN TEST



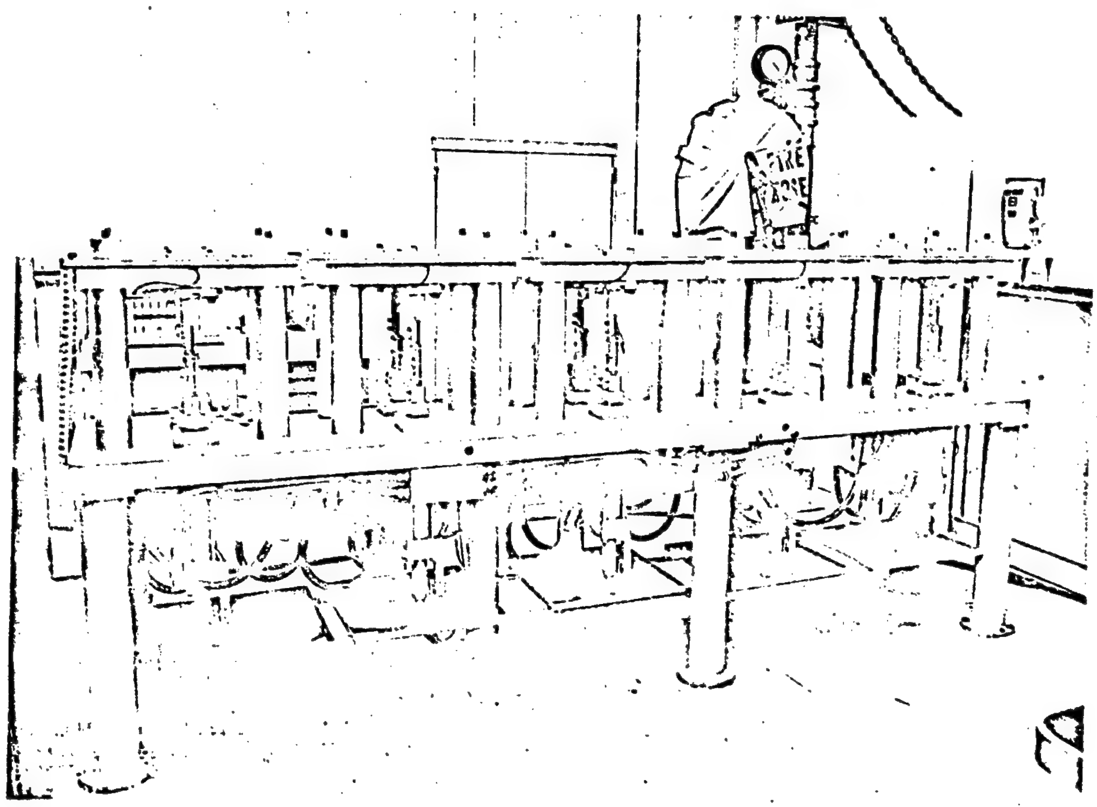
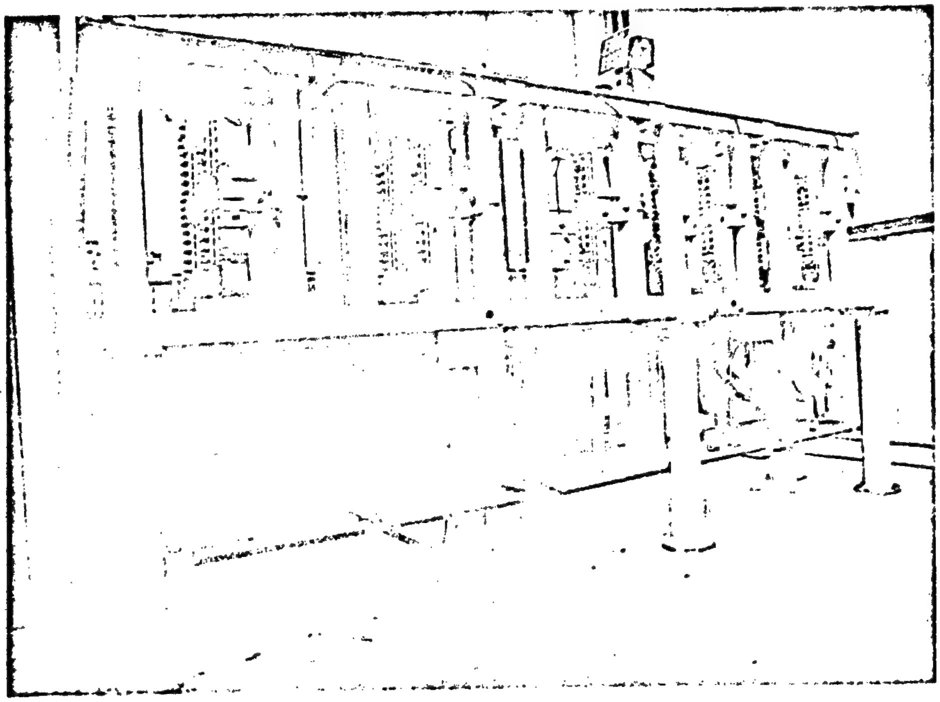
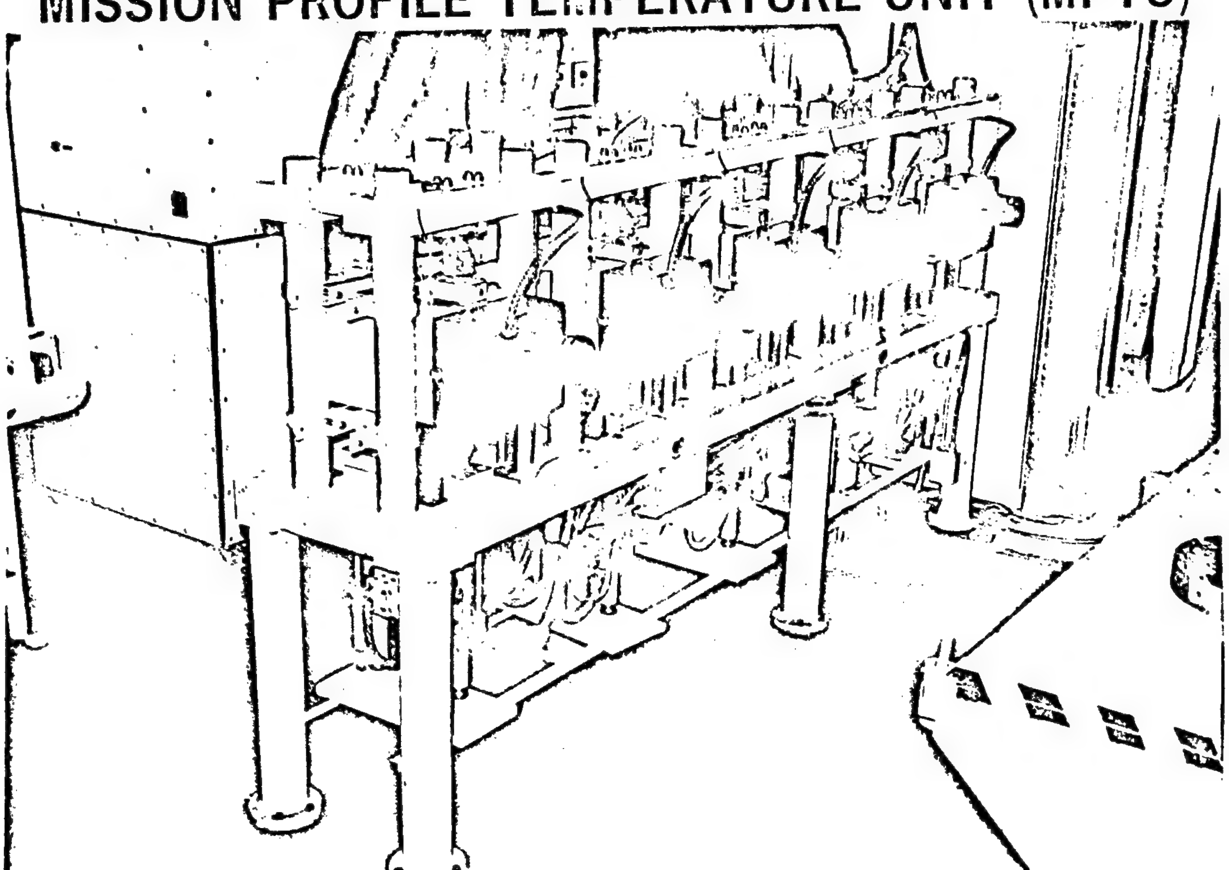


FIGURE 15. BOLTED JOINT MULTISPECIMEN TEST FIXTURE WITH SPECIMENS IN PLACE

RTD BONDED SPECIMEN FATIGUE TEST

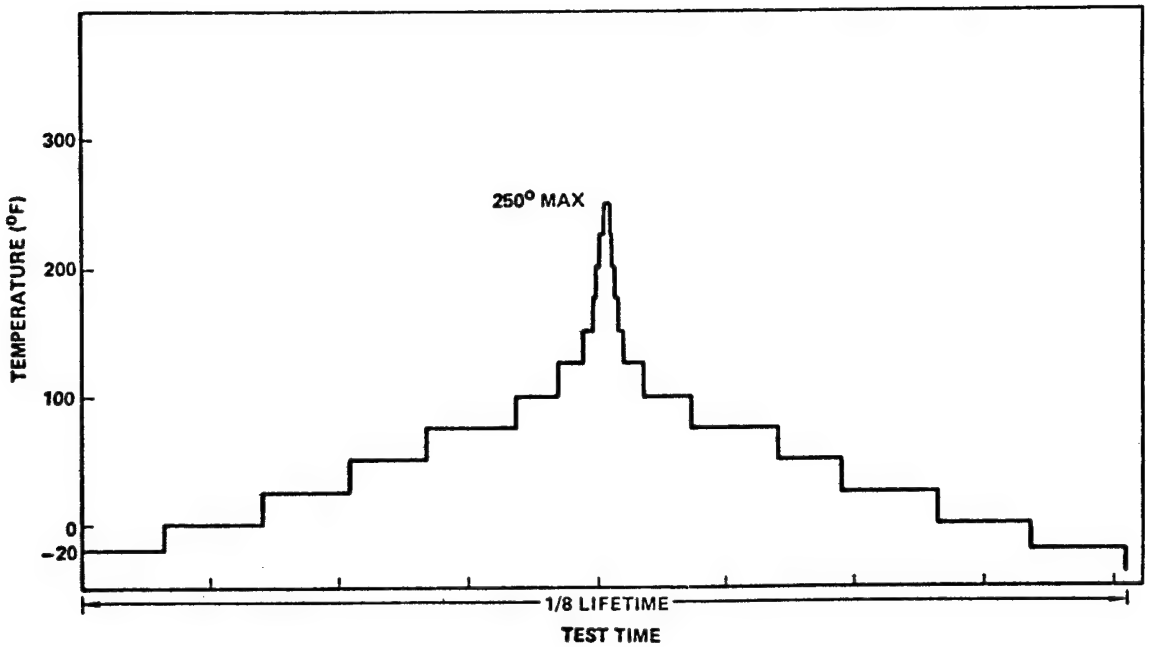


MISSION PROFILE TEMPERATURE UNIT (MPTU)



TEMPERATURE (°F) VERSUS NUMBERS OF MISSIONS

BLOCK LENGTH = 408 MISSIONS OR 1/8 LIFE



ACCELERATED ENVIRONMENTAL/ LOAD SPECTRUM MODEL

LOWER SURFACE (TENSION DOMINATED SPECTRUM)

BASELINE FIGHTER BASE: SEYMOUR-JOHNSON AFB, N.C. INCLUDES PRECIPITATION AND SOLAR ABSORPTIVITY (S.A. = 0.40) 27 PLY AS/3501-5 GRAPHITE/EPOXY

FIRST 1/4 LT

1. ACCELERATED RUNWAY STORAGE EXPOSURE WILL BE AS FOLLOWS: EXPOSURE OF COMPOSITE TO THE NECESSARY CONDITIONS TO ACHIEVE A MOISTURE ABSORPTION EQUIVALENT TO AN EXPOSURE OF:

   a. 6 HOURS @ 54.2°F/85.8% RH
   b. 6 HOURS @ 66.7°F/60.3% RH
   c. 6 HOURS @ 74.9°F/48.1% RH
   d. 6 HOURS @ 60.0°F/75.1% RH X 811
   e. 6 HOURS @ 54.2°F/85.8% RH
   f. 6 HOURS @ 66.7°F/60.3% RH
   g. 5.7 HRS @ 74.9°F/48.1% RH

   41.7 HRS TOTAL

   WHICH GIVES A MOISTURE CONTENT OF 0.49 IN % BY WEIGHT

2. ACCELERATED LOAD/TEMPERATURE SPECTRUM SIMULATING 811 FLIGHTS OF 1.2 HOURS DURATION AFTER COMPOSITE RUNWAY STORAGE EXPOSURE CONDITIONS WHICH GIVES A MOISTURE CONTENT OF 0.42 IN % BY WT.

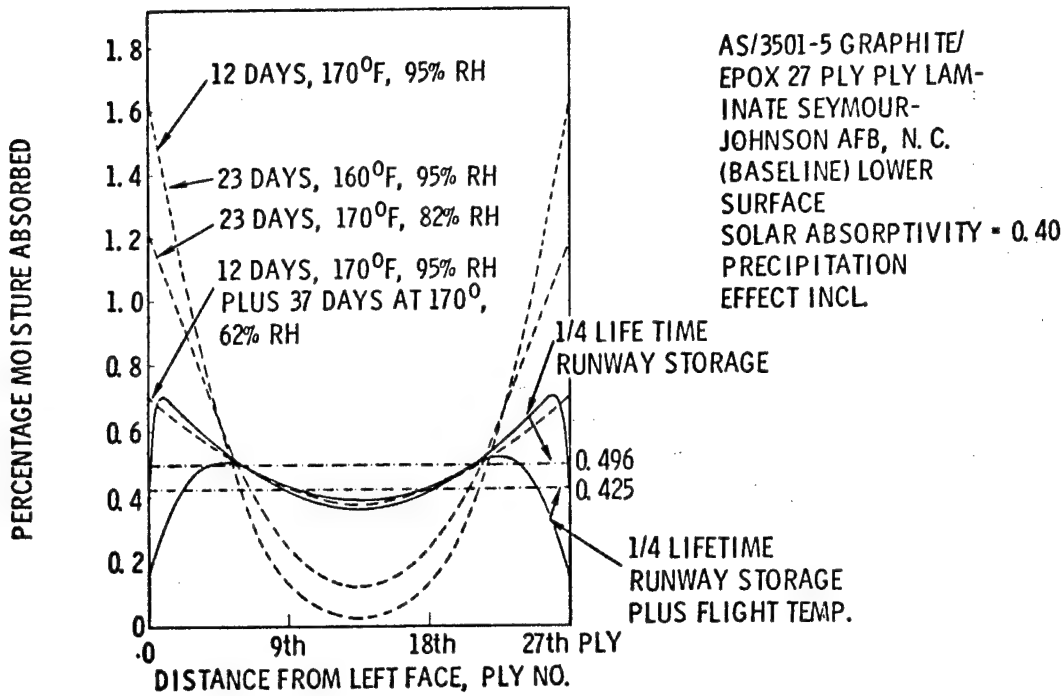
SECOND 1/4 LT

3. REPEAT NO. 1, RUNWAY STORAGE SPECTRUM TO GIVE A MOISTURE CONTENT OF 0.64 IN % BY WT.
4. REPEAT NO. 2 LOAD/TEMPERATURE – SPECTRUM TO GIVE A MOISTURE CONTENT OF 0.55 IN % BY WT.

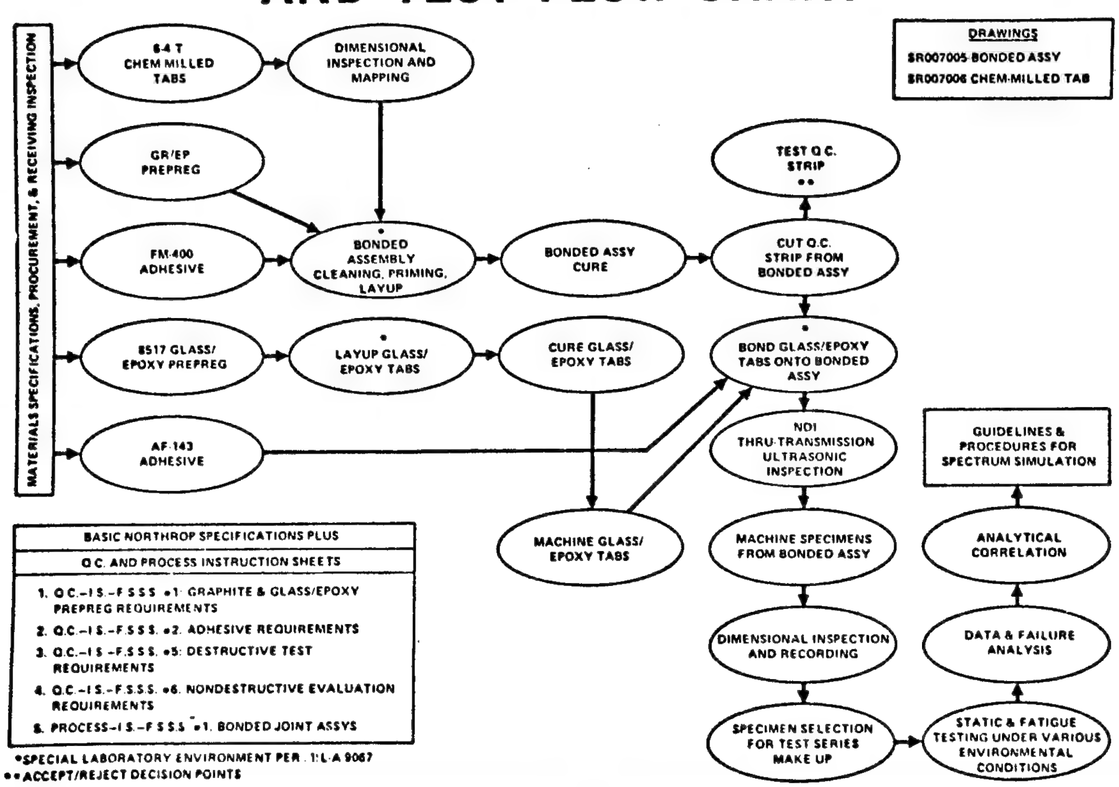
↓

ETC.

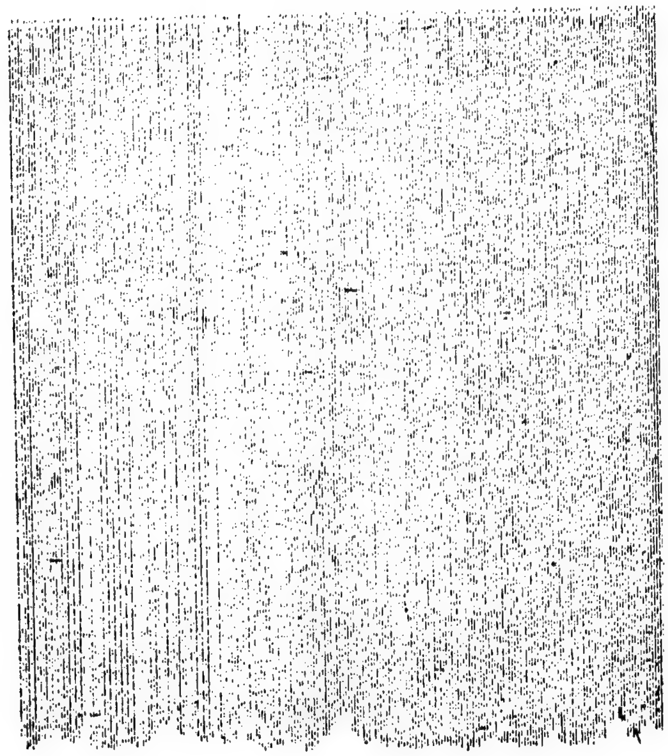
FIGHTER ONE QUARTER LIFETIME RUNWAY STORAGE/ FLIGHT TEMP EXP.



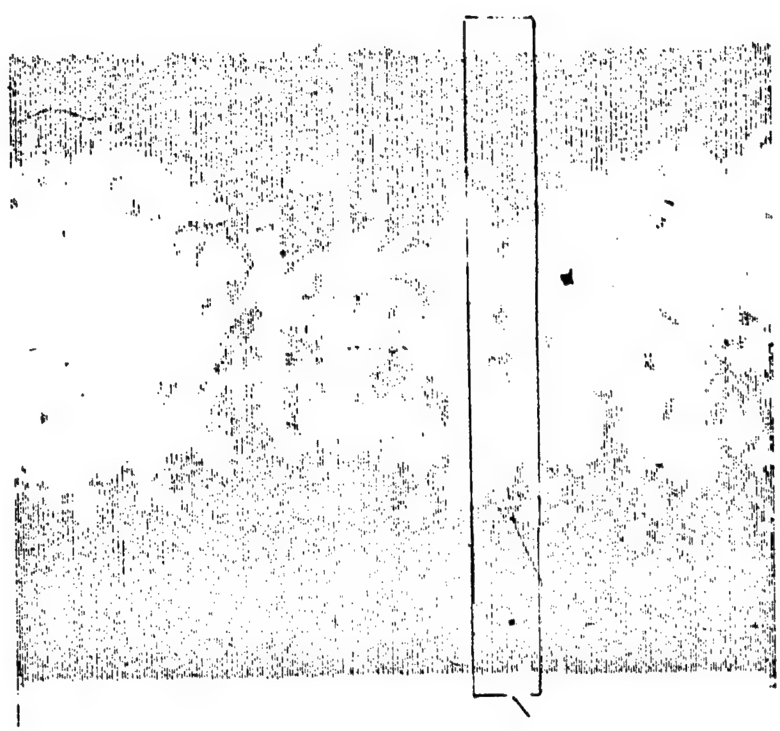
BONDED JOINT FABRICATION AND TEST FLOW CHART



CM-1 THRU-TRANSMISSION ULTRASONIC NDI RECORD



CM-4 THRU-TRANSMISSION ULTRA-SONIC NDI RECORD



PHOTOMICROGRAPHS OF DEFECT AREAS
(AS SHOWN ON NDI RECORDING)

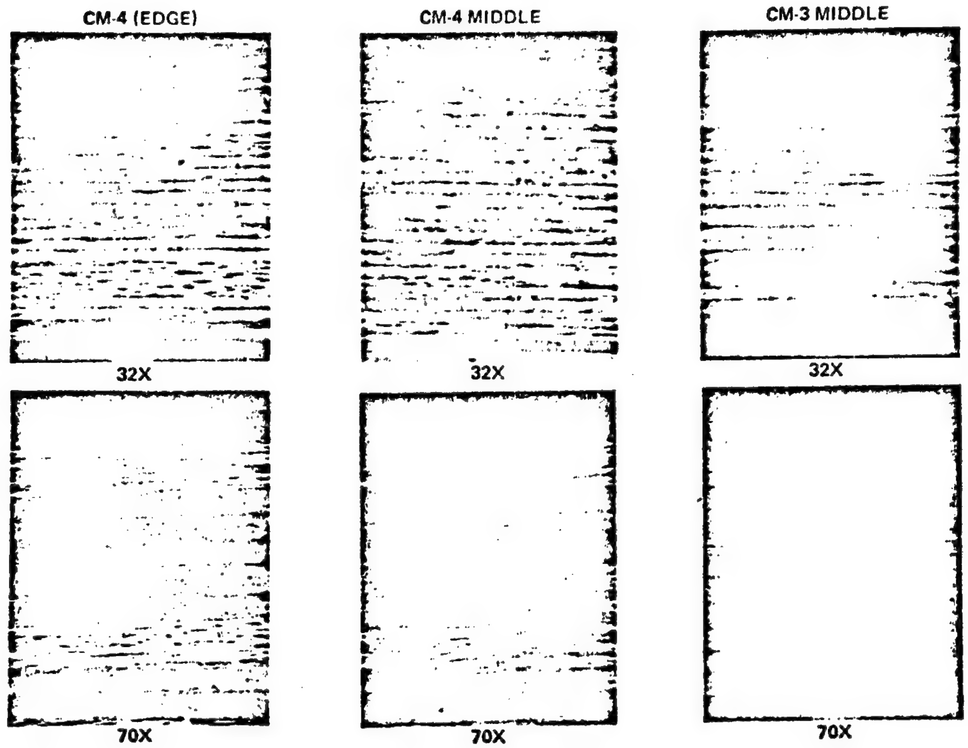


TABLE 7.

STATISTICAL SUMMARY OF TASK 1A BOLTED JOINT TEST RESULTS

TEST[1] SERIES	TYPE OF TEST	FREQUENCY (HERTZ)	LOADING RATE (Kips/sec)	NUMBER OF LIFETIMES	$\hat{a}$	95% CONFIDENCE SCALE PARAMETER	V $N_X(t)_R$
14	STATIC	--	--	--	25.54	10,021	9,175
15	FATIGUE	5.0	VARIABLE	2	15.05	9,828	8,463
16	↓	5.0	VARIABLE	1	15.59	10,055	8,705
17	↓	0.5	VARIABLE	2	21.55	9,868	8,890
18	↓	VARIABLE	12.0	2	18.11	10,049	8,875
19	↓	VARIABLE	1.2	2	18.18	10,029	8,919
20[2]	↓	VARIABLE	12.0	2	15.82	10,192	8,841
21	↓	REAL	REAL	1	15.39	9,920	8,570

1. 20 SPECIMENS PER SERIES EXCEPT 10 SPECIMENS IN SERIES 21, 40 SPECIMENS IN TEST SERIES 15
2. WITH DWELL TIMES AT PEAK LOADS

SUMMARY OF TASK IB BOLTED JOINT TEST RESULTS

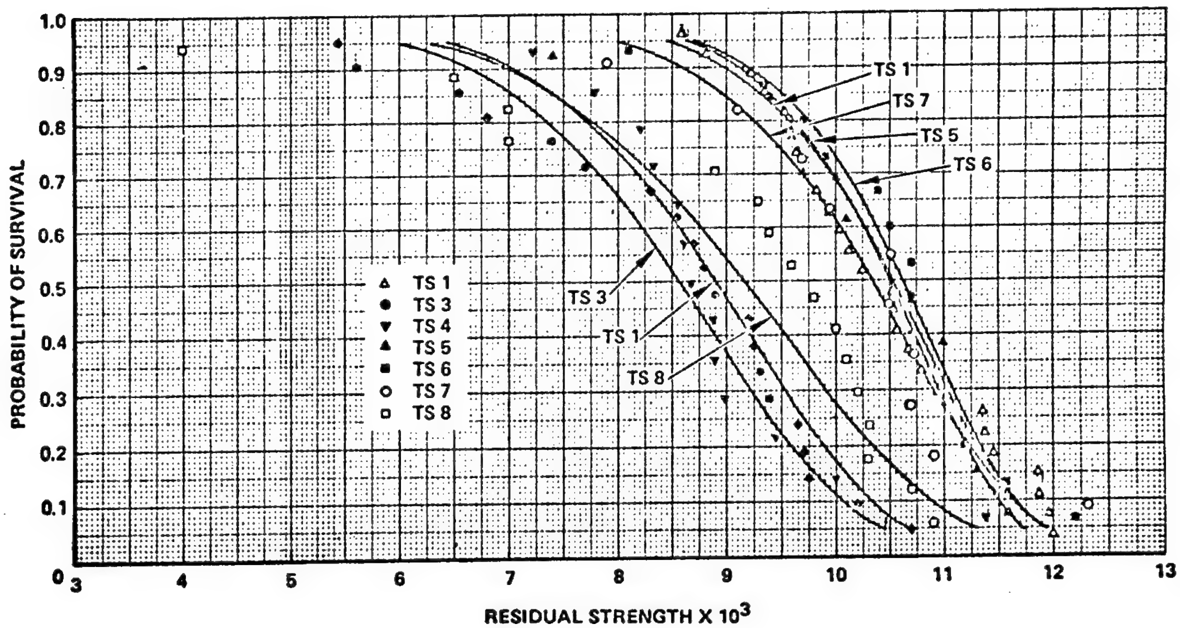
TEST SERIES	TYPE OF TEST	FREQUENCY hertz	RMS MULTI-PLICATION FACTOR	NUMBER OF LIFETIMES	$\hat{a}$	95 PERCENT CONFIDENCE SCALE PARAMETER lbs/inch	$N_x^t(t)_R$ lbs/inch
14	STATIC	–	–	–	25.54	10,021	9,175
15	FATIGUE	5	1.000	2	15.05	9,828	8,463
26	FATIGUE	5	1.302	2	27.34	10,118	9,319
27	FATIGUE	5	1.500	2	26.60	9,890	9,088

STATISTICAL SUMMARY OF TASK 1A
BONDED JOINT$^{\phi}$ TEST RESULTS
(CENSORED DATA)*

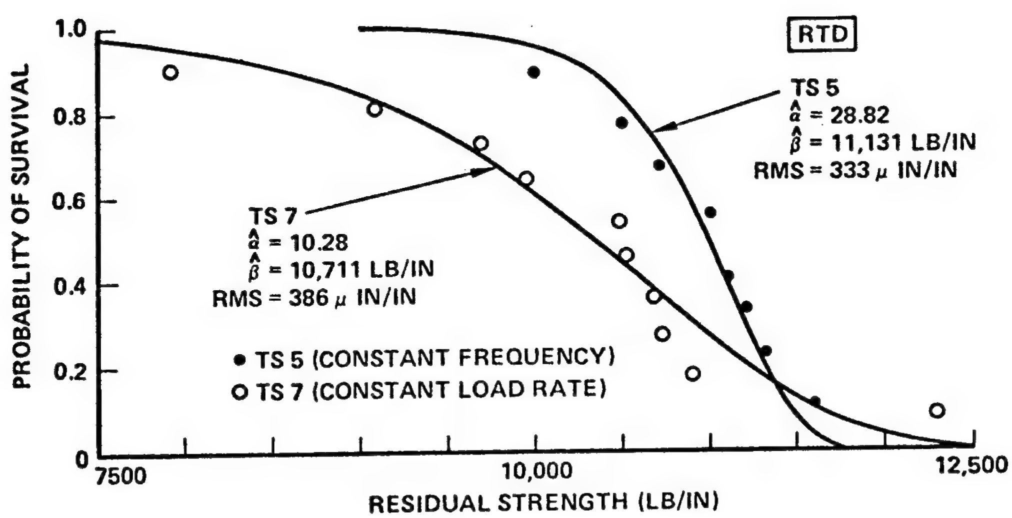
TEST SERIES	TYPE OF TEST	FREQUENCY (HERTZ)	LOADING$^{\theta}$ RATE (KIPS/SEC)	NUMBER OF LIFETIMES	NO. OF REPLI-CATES	$\hat{\alpha}$	SCALE FACTOR $\hat{\beta}$	95% CONFIDENCE SCALE PARAMETER $\breve{\beta}$	$\breve{N}_X^t(t)_R$
1	STATIC	–	–	–	26	11.90	10,852	10,584	8760
3	FATIGUE	5	VARIABLE	2	19	7.38	9,006	8,601	6340
4	FATIGUE	5	VARIABLE	1	12	8.00	9,315	8,842	6674
5	FATIGUE	0.5	VARIABLE	2	12	13.18	10,800	10,464	8821
6	FATIGUE	VARIABLE	12	2	14	12.99	10,920	10,392	8739
7	FATIGUE	VARIABLE	1.2	2	10	10.28	10,711	10,251	8236
8	FATIGUE	VARIABLE	12+DTPL	2	16	6.95	9,652	9,156	6625

*FATIGUE FAILURES AT < 2LT WERE CENSORED
θMAX. FATIGUE SPECTRUM LOADING 5850 LBS
ϕTYPE B SPECIMEN

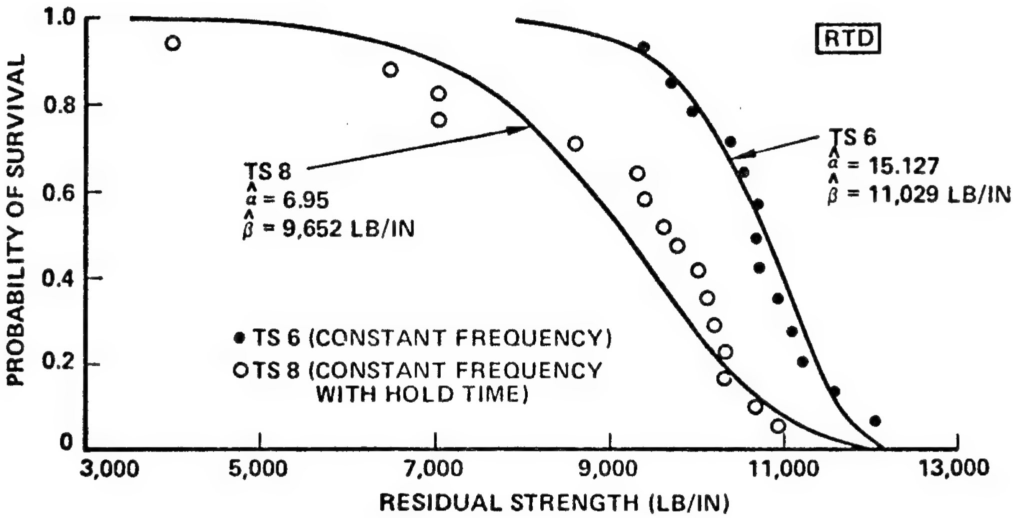
TASK IA BONDED JOINT TEST DATA



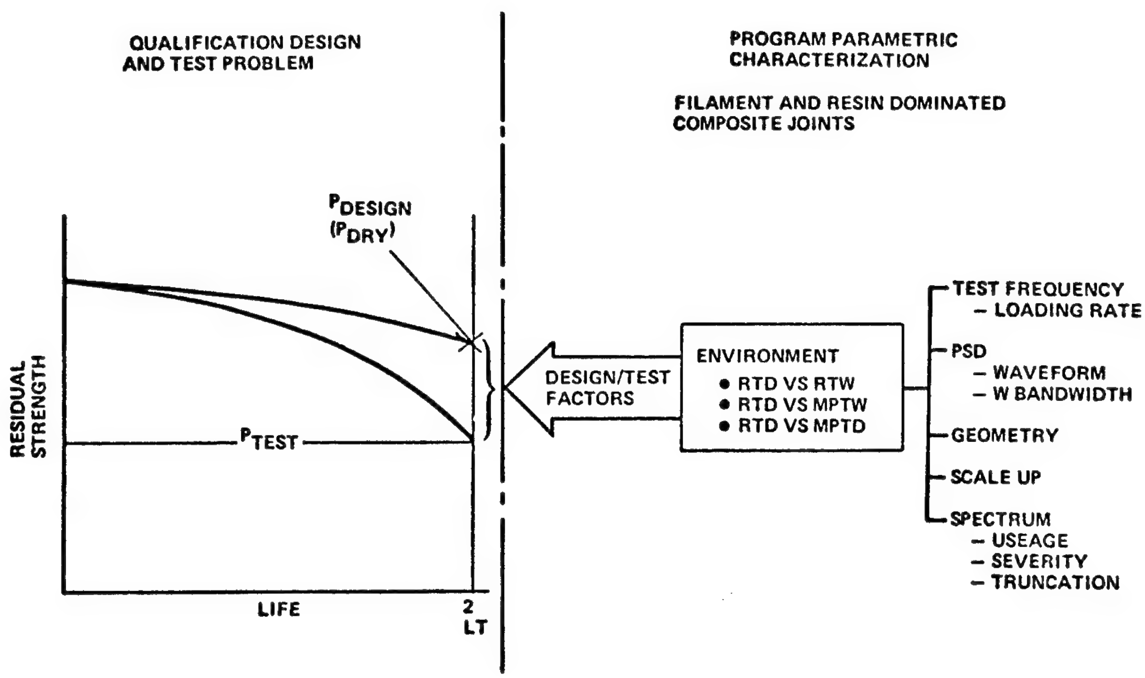
BONDED JOINT TEST RESULTS
F33615-75-C-5236, FATIGUE SPECTRUM SENSITIVITY STUDY FOR ADVANCED COMPOSITES



BONDED JOINT TEST RESULTS
F33615-75-C-5236, FATIGUE SPECTRUM SENSITIVITY STUDY FOR ADVANCED COMPOSITES



FATIGUE SPECTRUM SENSIVITY STUDY PAYOFF



Environmental Sensitivity of Advanced Composites

Contract No. F35615-76-C-5324

Air Force Flight Dynamics Laboratory
Grumman Aerospace Corporation

GRUMMAN

PROGRAM OBJECTIVES

- DEFINE REALISTIC ENVIRONMENTAL SPECTRA FOR AIR FORCE AIRCRAFT
  - FIGHTERS
  - BOMBERS
  - CARGO/TANKERS
- ASSESS DURABILITY SENSITIVITY OF COMPOSITES TO VARIOUS ENVIRONMENTAL PARAMETERS
  - LONG TERM EXPERIMENTS
  - TIME
  - TEMPERATURE
  - RELATIVE HUMIDITY
- DETERMINE EFFECTS OF ACCELERATING ENVIRONMENTAL SPECTRA
  - ANALYSIS AND EXPERIMENT
  - DEVELOP METHODOLOGY FOR ECONOMICAL ALTERNATIVES TO REAL-TIME TESTING

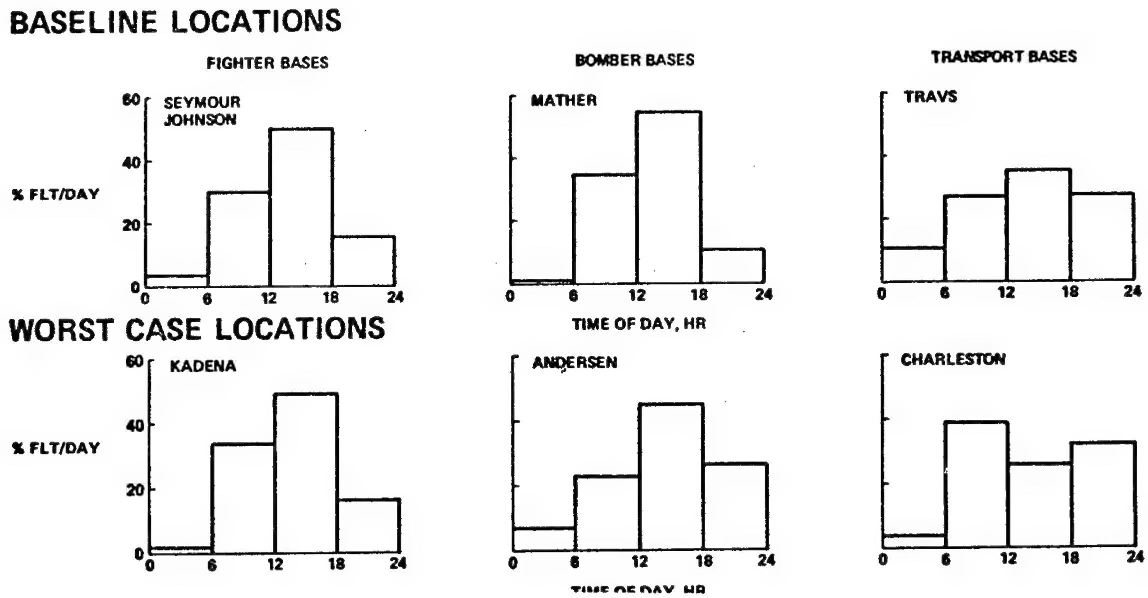
RUNWAY STORAGE MODEL

- SURVEY AF BASES HAVING PSYCHOMETRIC SUMMARIES
- SURVEY AF BASES TO SELECT MOST ACTIVE BASES
- SELECT 20 REPRESENTATIVE BASES PER A/C TYPES WITH ADEQUATE WEATHER & BASING DATA
- FOR EACH A/C TYPE RANK BASES ACCORDING TO ABSORPTION OF WATER FOR MEAN WEATHER COND'NS
- SELECT BASELINE, WORST CASE LOCATIONS
- OBTAIN COMPLETE CLIMATIC SUMMARIES
- OBTAIN BASING DATA
- COMPUTE MODELS OF TEMP, RH & SOLAR RAD FOR EACH BASE

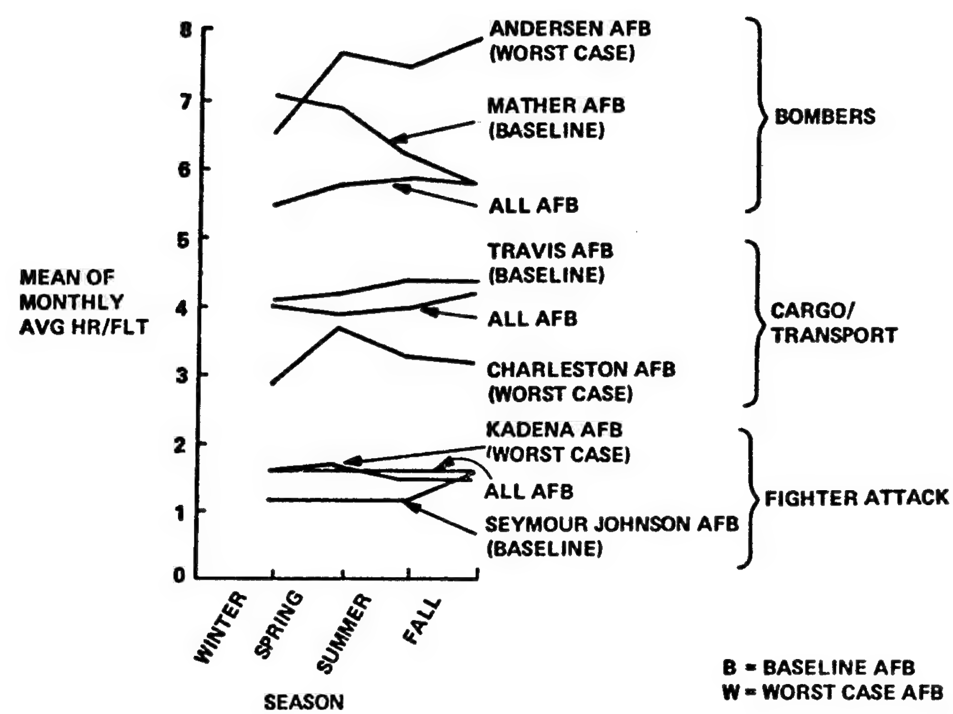
SELECTION SUMMARY

	BASELINE	WORST CASE
FIGHTER	SEYMOUR JOHNSON, NORTH CAROLINA	KADENA, JAPAN
BOMBER	MATHER, CALIFORNIA	ANDERSEN, GUAM
TRANSPORT	TRAVIS, CALIFORNIA	CHARLESTON, SOUTH CAROLINA

AIRCRAFT USAGE – TIME OF DAY



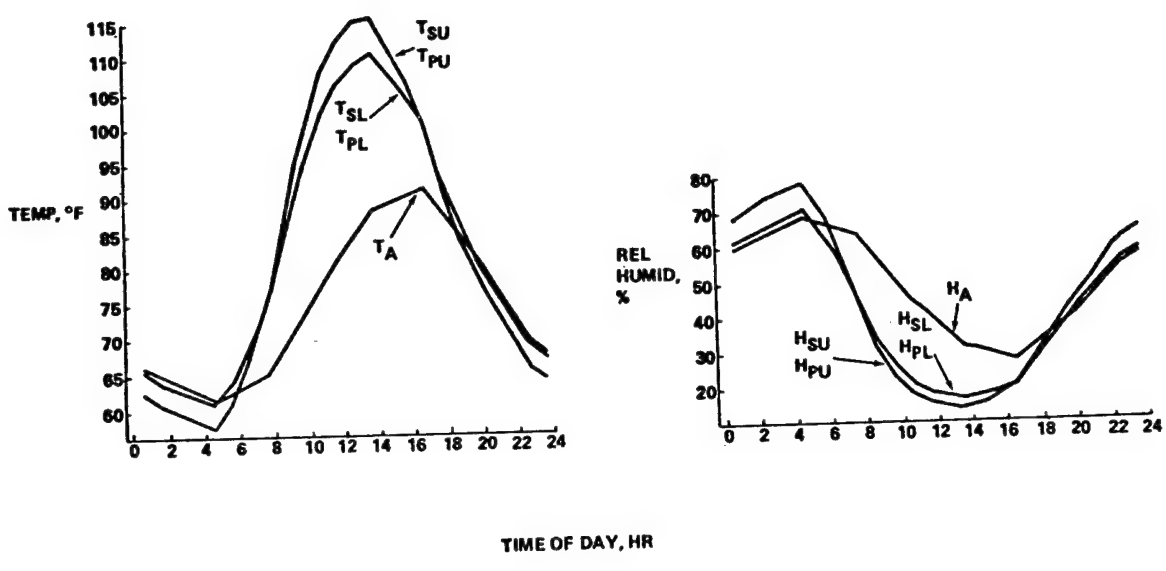
AIRCRAFT USAGE – FLIGHT DURATION BY SEASON



RUNWAY STORAGE MODEL DATA INPUTS

- TEMPERATURE
  - DRY BULB TEMPERATURE
- HUMIDITY
  - RELATIVE HUMIDITY
  - PRECIPITATION
- SOLAR
  - CLEAR SKY ISOLATION
  - CLOUDS
  - HAZE/SMOKE
  - DEW POINT
  - WIND SPEED

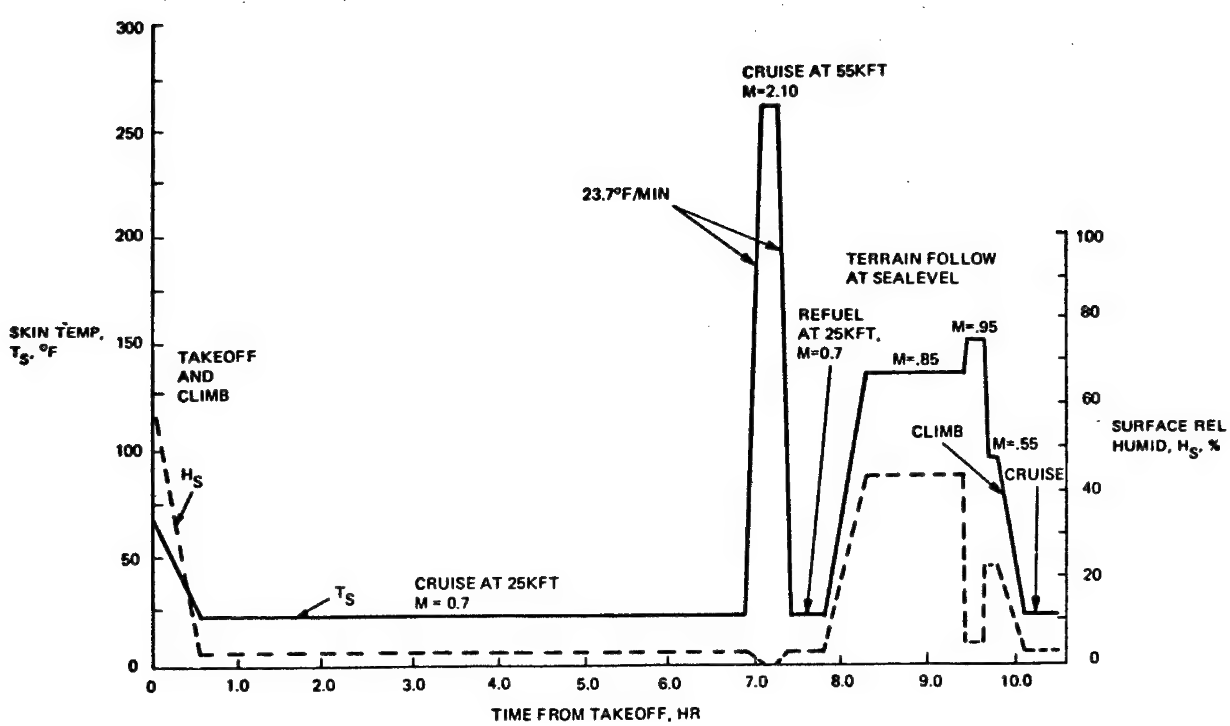
RUNWAY STORAGE MODEL, JULY COMPONENT $\alpha = .4$: MATHER AFB



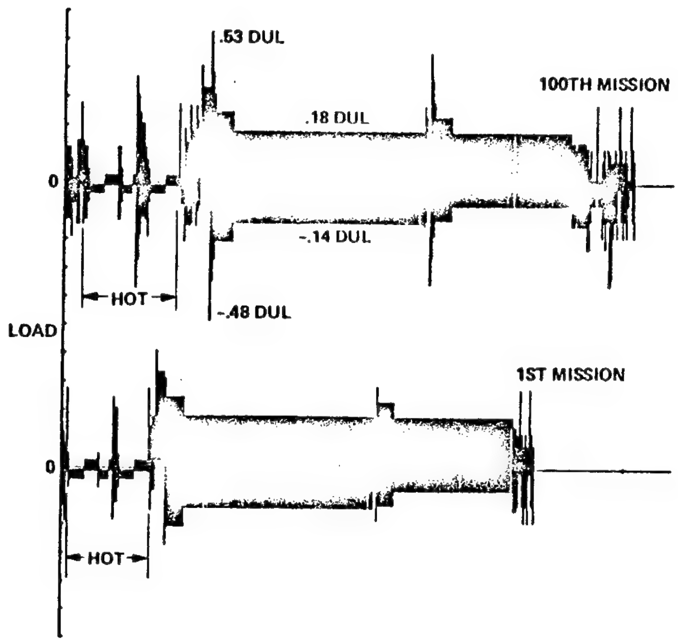
COMPONENT SELECTION

- B-1 COMPOSITE HORIZONTAL STABILIZER
- GR/EP SUBSTRUCTURE 6 TO 32 PLIES THICK
- HYBRID COVER 36 TO 104 PLIES THICK – MAJOR PORTION 36-PLY GR/EP
- 260°F DESIGN TEMPERATURE

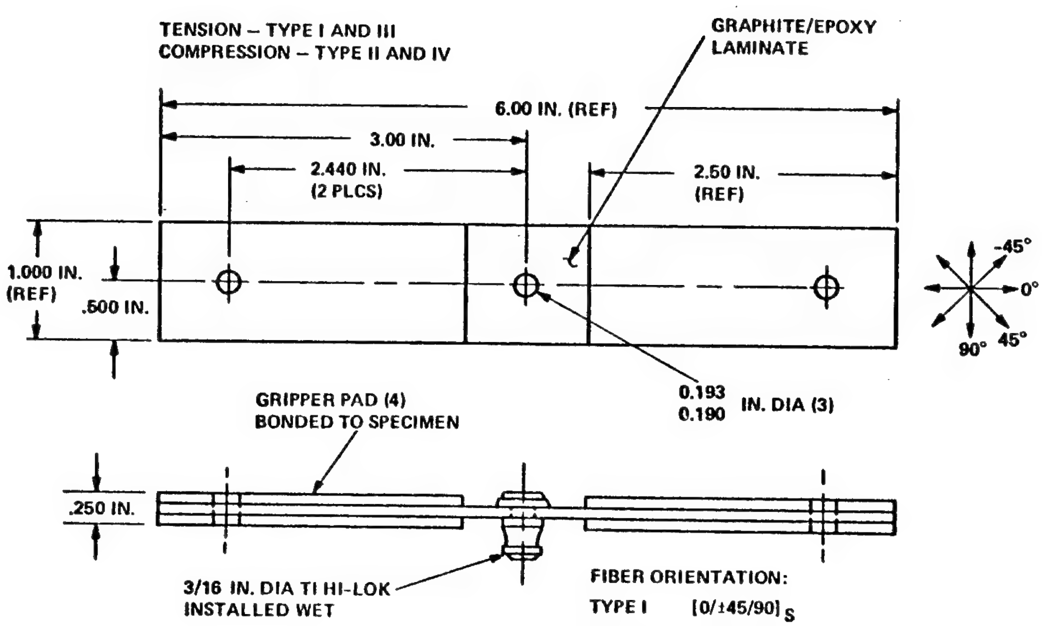
FLIGHT THERMAL PROFILE



STABILIZER TENSION SKIN LOAD SPECTRUM



TEST SPECIMEN



FIBER ORIENTATION:

TYPE I	$[0/\pm45/90]_S$
TYPE II	$[0/\pm45/0]_S$
TYPE III	$[0/\pm45/90_2/\mp45/0]_S$
TYPE IV	$[0/\pm45/0_2/\mp45/0]_S$

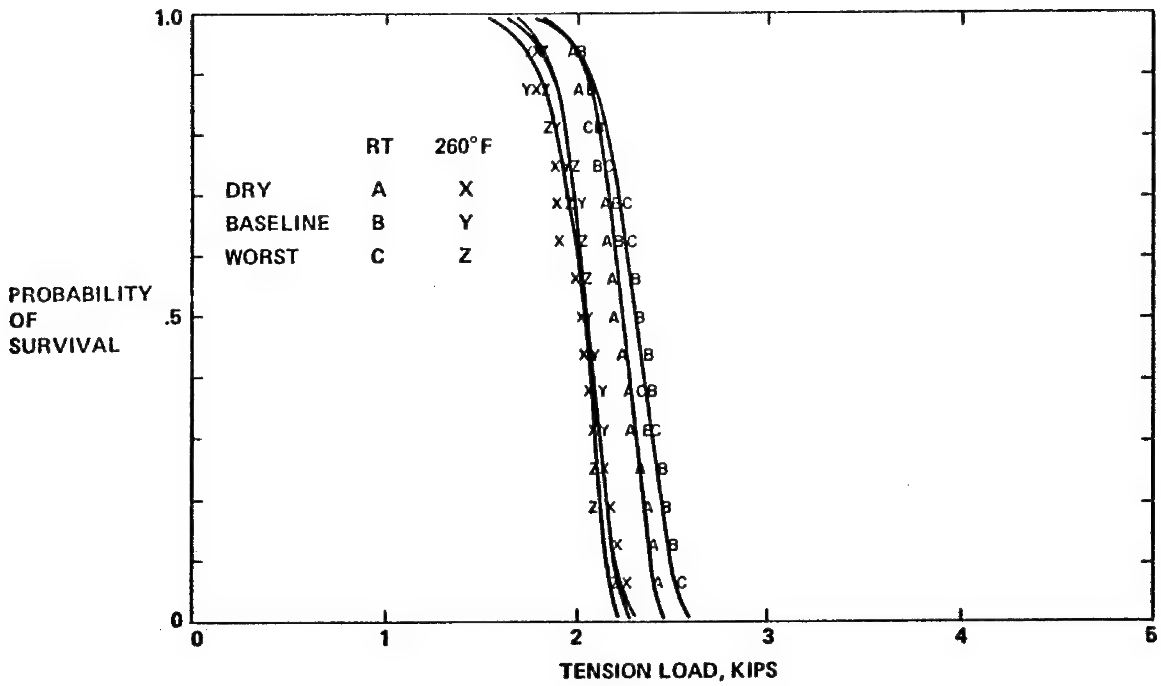
TEST PLAN

- STATIC CHARACTERIZATION
  - 360 SPECIMENS, 120 EACH, 4 TYPES
  - RT AND 260°F
  - DRY, BASELINE, AND WORST CASE MOISTURE LEVELS
  - 15 REPLICATES
  - STATUS: COMPLETE
- NOMINAL FATIGUE
  - 240 SPECIMENS, 60 EACH, 4 TYPES
  - 6 A/C LIFETIMES + RT RESIDUAL (AMB. MOISTURE)
  - 4 REF. STRESS LEVELS
  - STATUS: IN PROGRESS

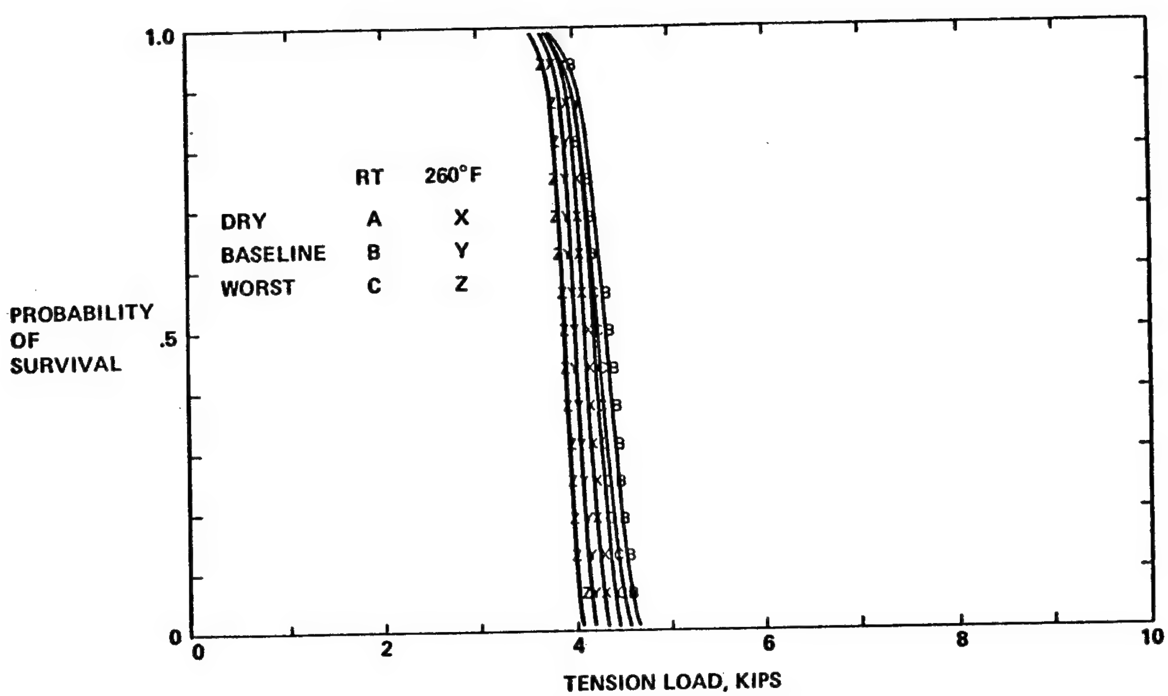
TEST PLAN (CONT'D)

- REAL TIME TESTS
  - 760 SPECIMENS
  - HOUR-BY-HOUR GROUND AND FLIGHT TEMP/HUM (BASELINE AND WORST CASE)
  - EXPOSURES AT 2, 5, 8, 12 AND 20 MOS + RESIDUALS
  - NO LOAD AND GROUND LOAD + FLIGHT LOADS
  - STATUS: SETTING UP
- ACCELERATED TESTS
  - 580 SPECIMENS
  - BASELINE AND WORST-CASE MOISTURE LEVELS BY PRESOAK & RESOAK OR CONDITION WHILE TEST
  - WITH AND WITHOUT SUPERSONIC TEMPS
  - 6 A/C LIFETIMES + RT RESIDUALS
  - STATUS: SETTING UP

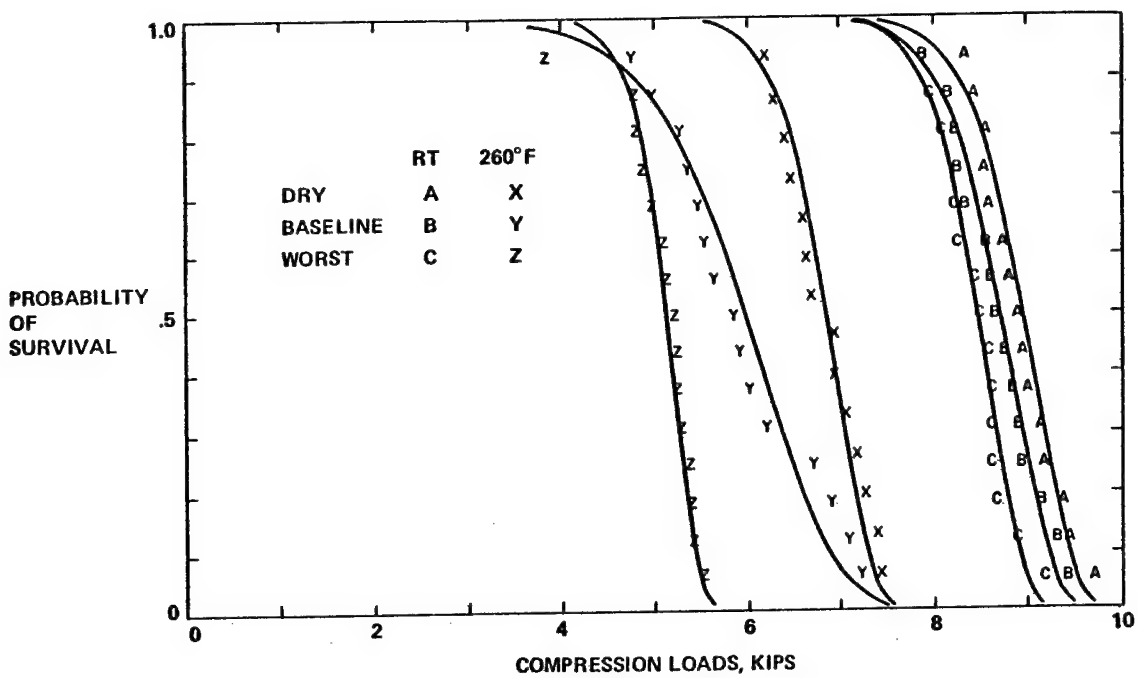
STATIC STRENGTH DISTRIBUTION OF TYPE I SPECIMENS



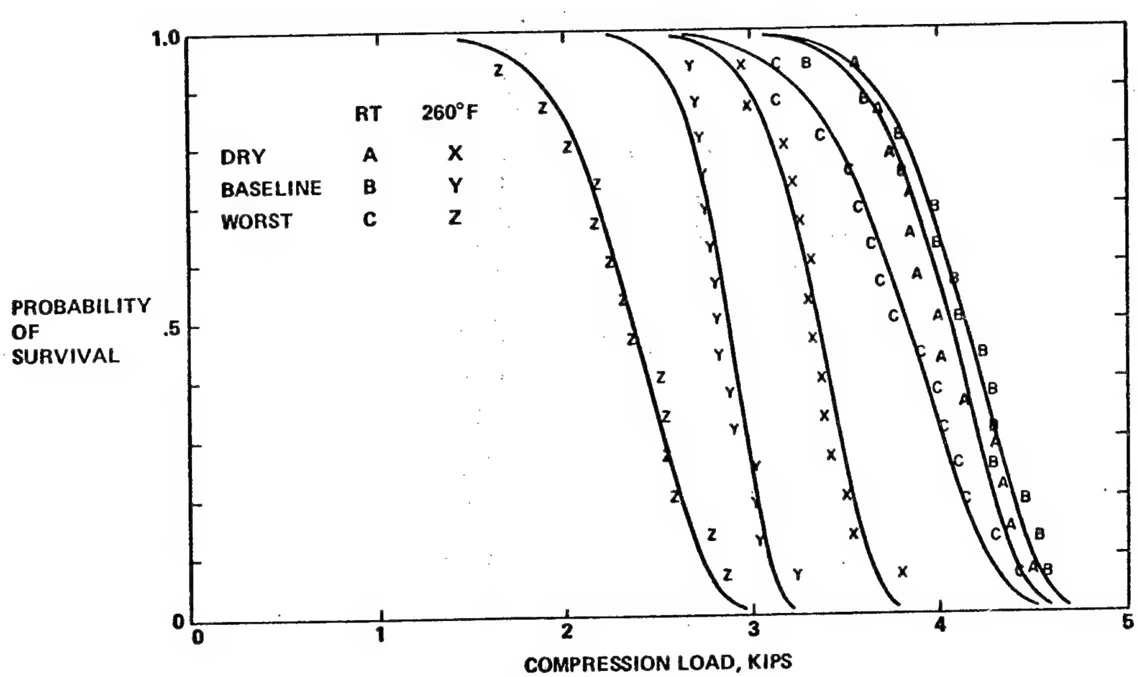
STATIC STRENGTH DISTRIBUTION OF TYPE III SPECIMENS



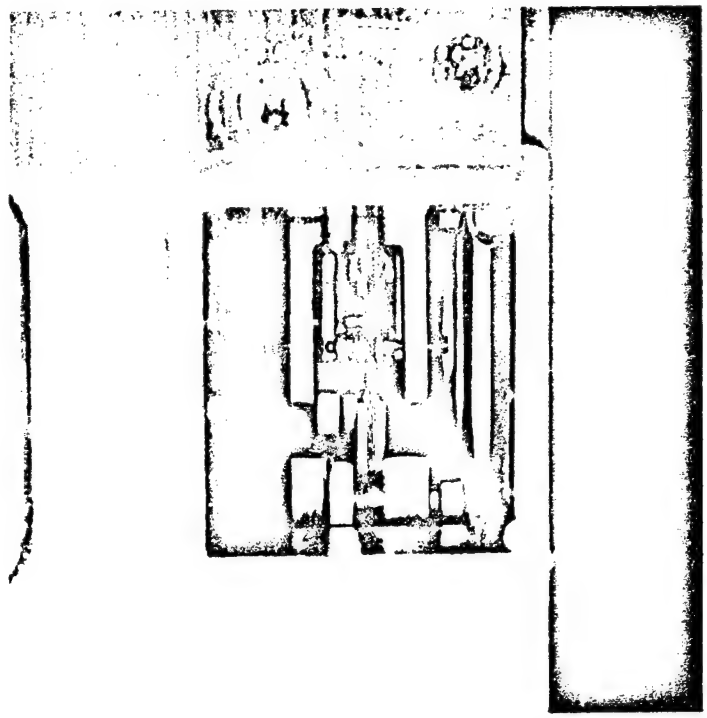
STATIC STRENGTH DISTRIBUTION OF TYPE IV SPECIMEN



STATIC STRENGTH DISTRIBUTION OF TYPE II SPECIMENS



STABILIZED FATIGUE TEST SPECIMEN



NOMINAL FATIGUE CHARACTERIZATION

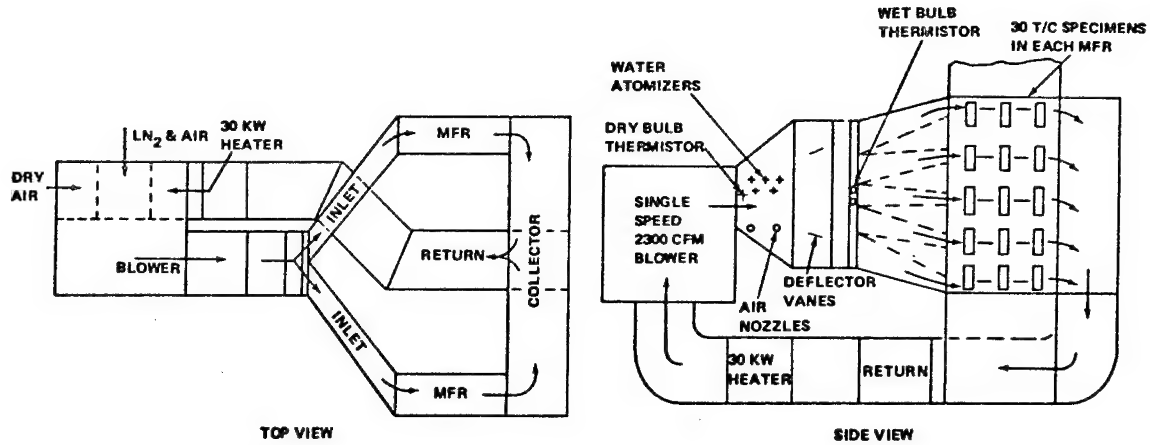
SAMPLES (ROOM TEMP TESTS)		TENSION TYPE I 2/2/4		COMPRESSION TYPE II 4/0/4		TENSION TYPE III 4/4/8		COMPRESSION TYPE IV 8/0/8	
		$\hat{\beta}$	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\alpha}$
PRESOAKED STATICS	DRY	2.29	21.8	4.16	15.6	4.32	29.6	9.10	23.9
	BASELINE	2.38	16.9	4.25	15.4	4.41	28.3	8.87	22.2
	WORST	2.38	16.6	3.96	11.7	4.28	37.0	8.61	25.5
AFTER 6 A/C LIVES LAB AMB	1.0 x DES STRESS	2.42	22.2	3.99	20.4	4.44	37.0	8.98	27.0
	1.2 x DES STRESS	2.42	17.4	4.24	13.8	4.53	21.4	8.64	23.3
	1.4 x DES STRESS	–	–	–	–	–	–	–	–
	1.65 x DES STRESS	–	–	–	–	–	–	–	–

$\hat{\beta}$ = SCALE PARAMETER (KIPS)

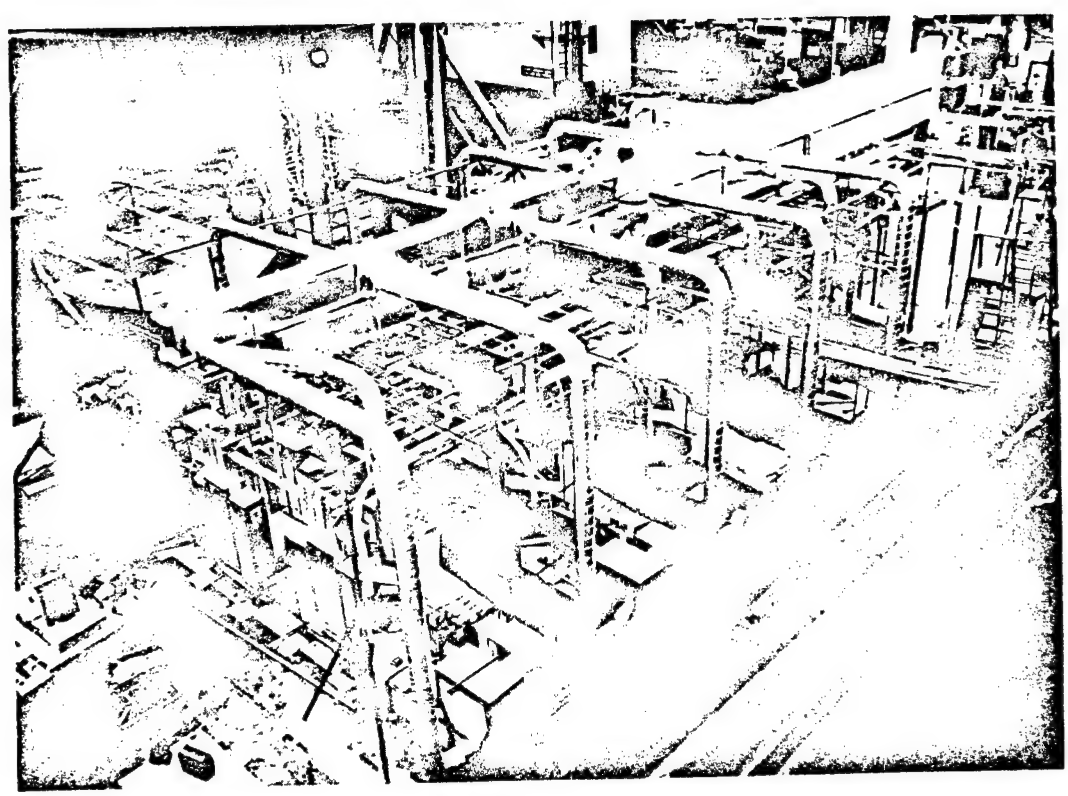
$\hat{\alpha}$ = SHAPE PARAMETER

MAXIMUM LIKELIHOOD ESTIMATES FOR TWO-PARAMETER WIEBULL DISTRIBUTION

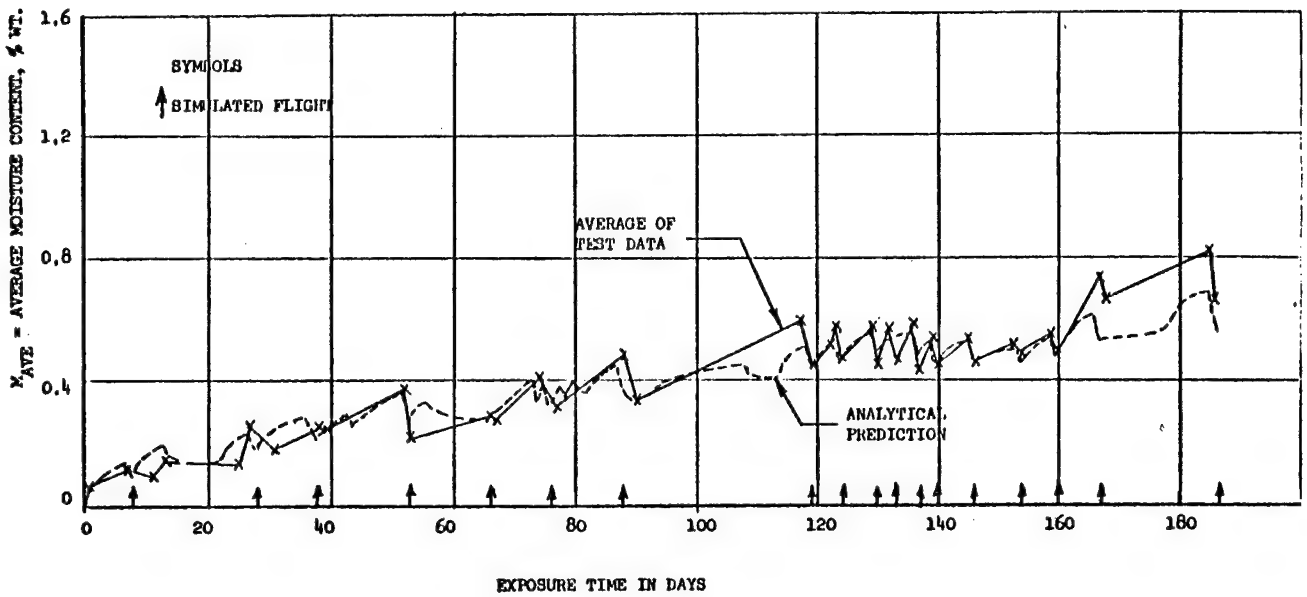
ENVIRONMENTAL SENSITIVITY CONDITIONING SYSTEM



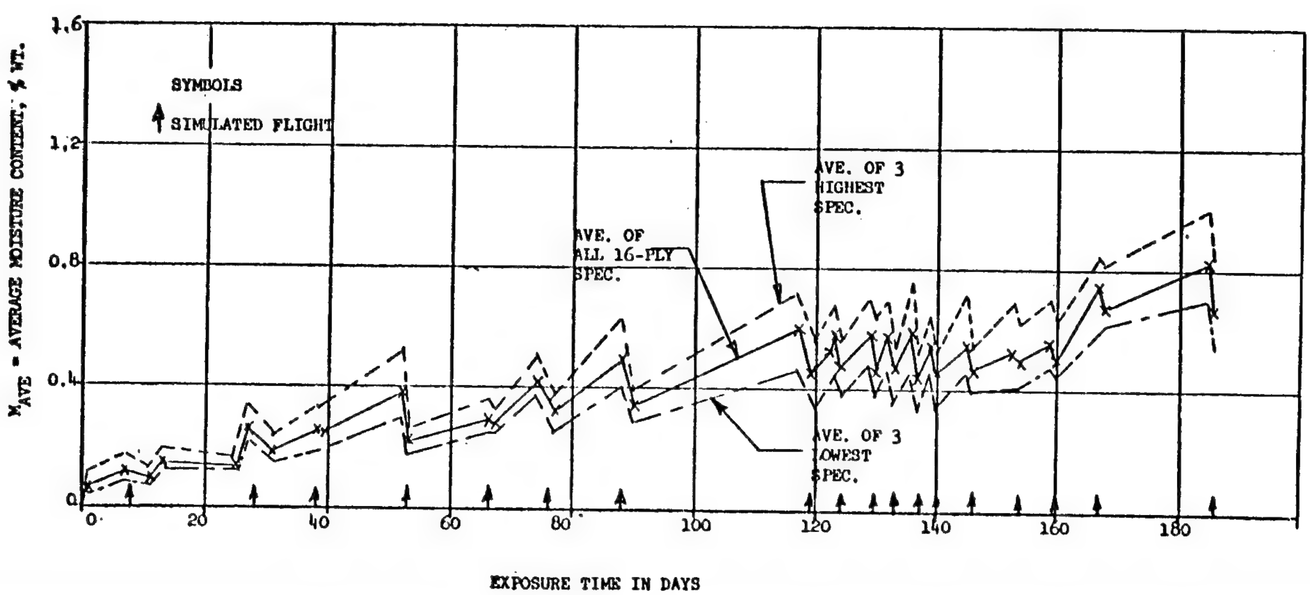
ENVIRONMENTAL TEST SETUP



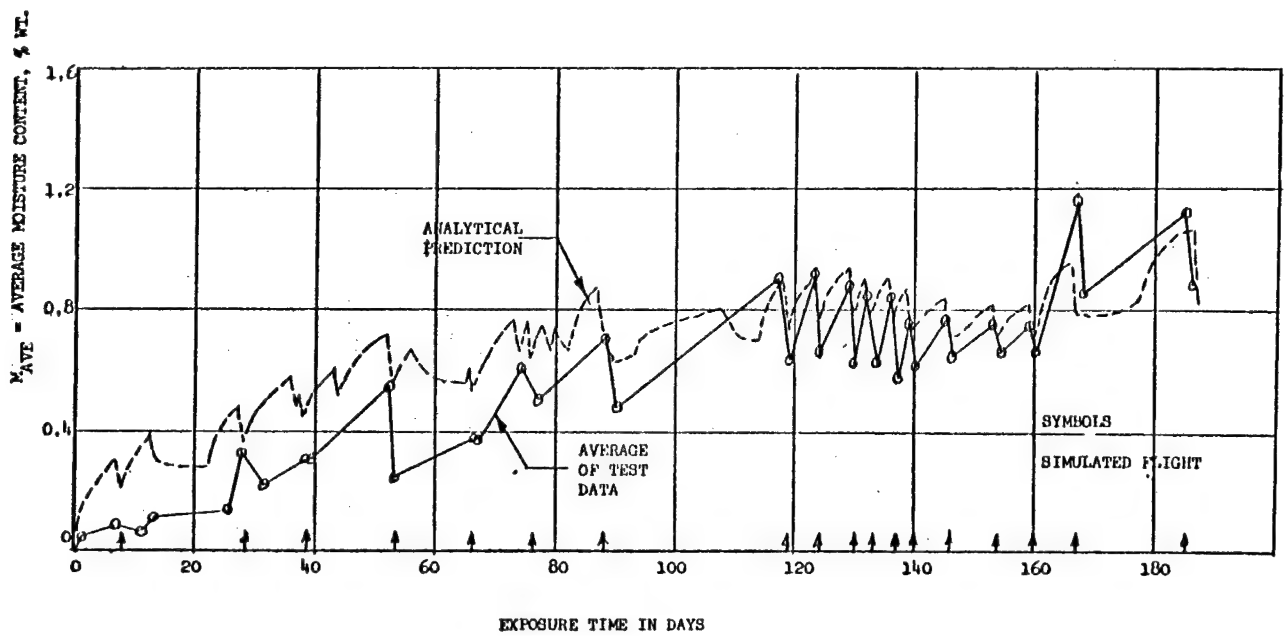
PREDICTION UNDER TEST ENVIRONMENT VS. TEST DATA FOR 16 PLY GR/EP,
BASELINE ENVIRONMENT, UNIT E-9, 12/9/78 TO 6/13/78



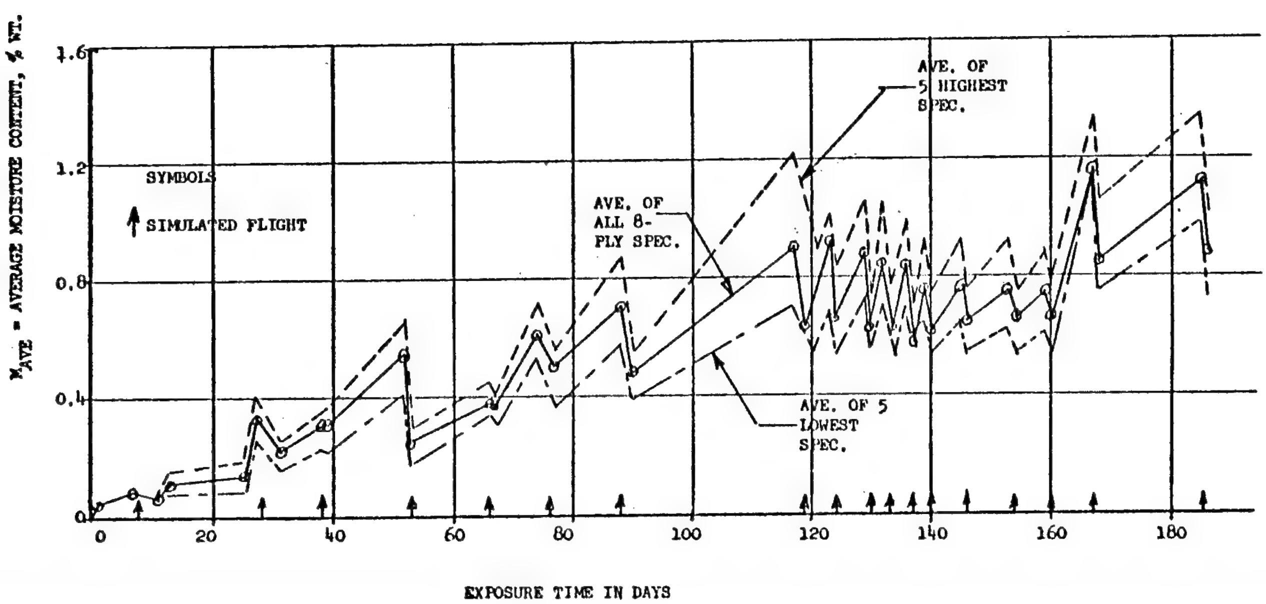
MOISTURE ABSORPTION DATA HISTORY, 16 PLY GR/EP
BASELINE ENVIRONMENT, UNIT E-9, 12/9/77 TO 6/13/78



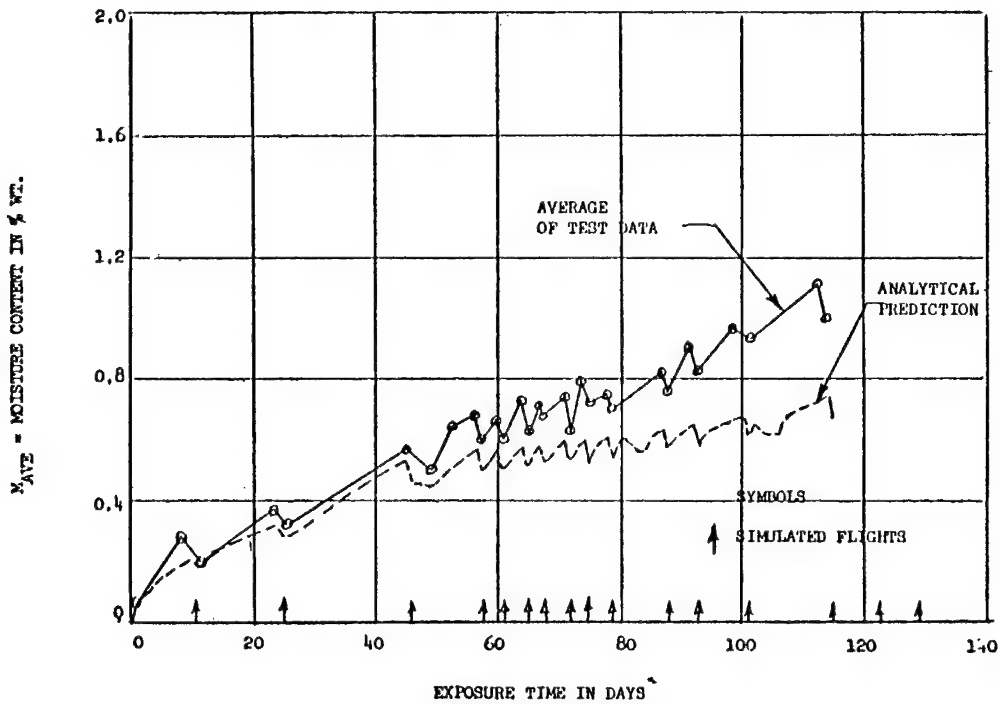
PREDICTION UNDER TEST ENVIRONMENT VS. TEST DATA FOR 8 PLY GR/EP,
BASELINE ENVIRONMENT, UNIT E-9, 12/9/78 TO 6/13/78

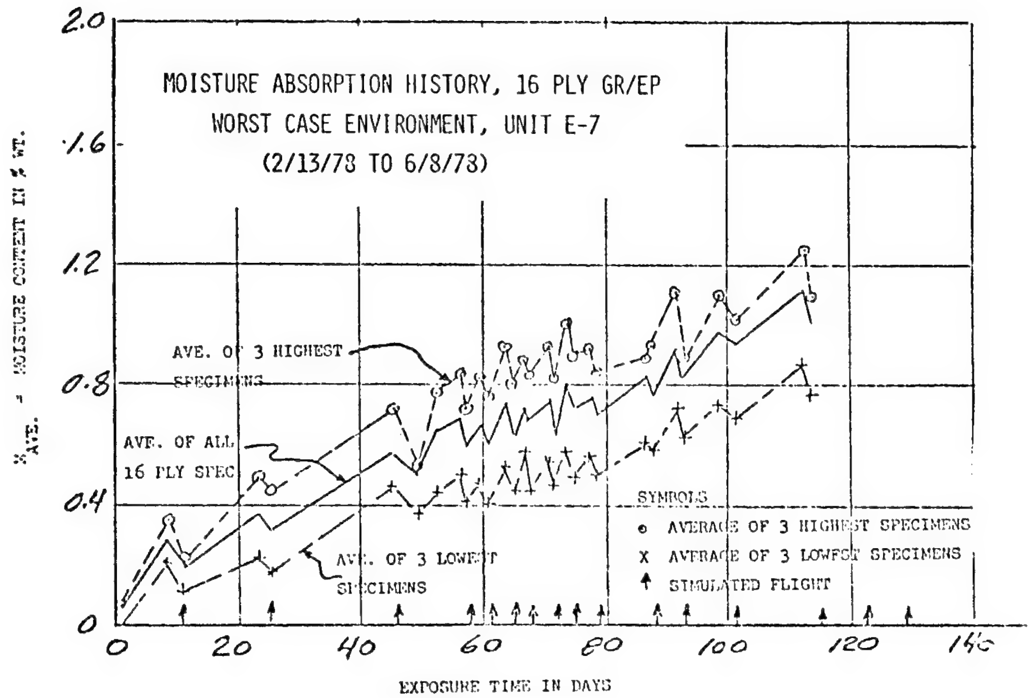


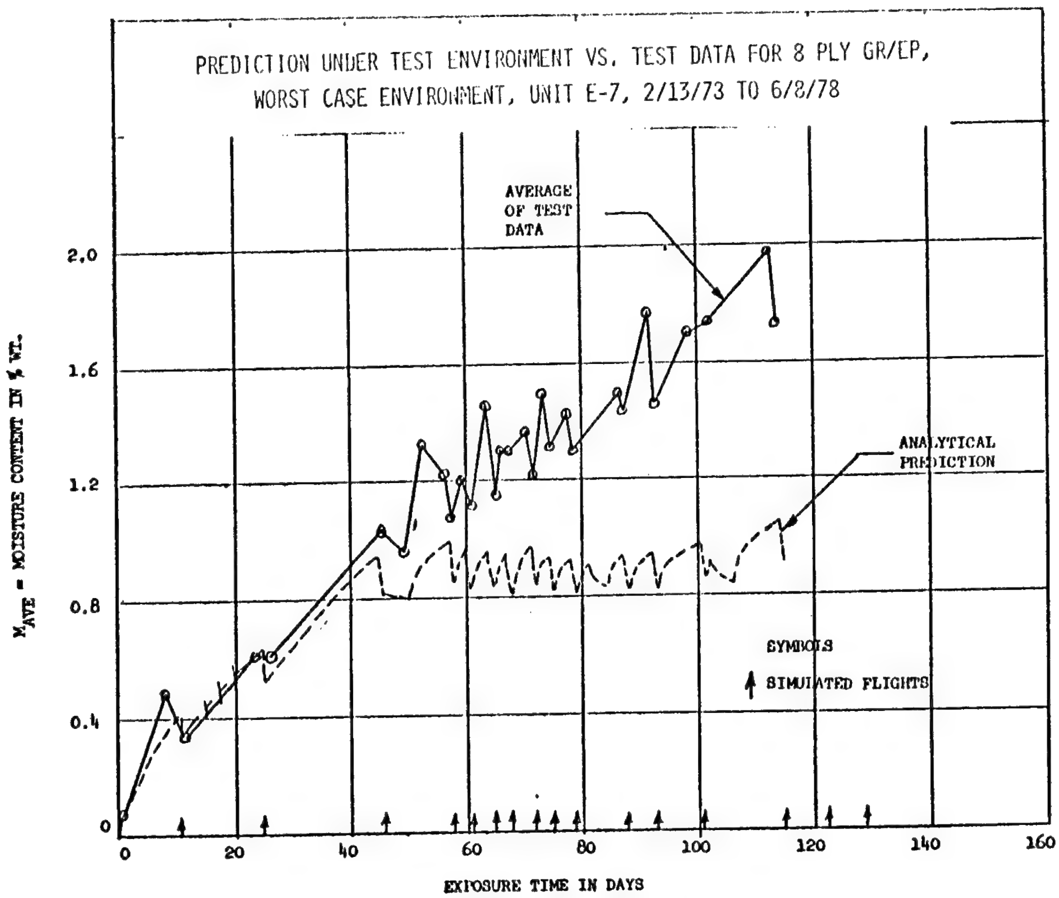
MOISTURE ABSORPTION DATA HISTORY, 8 PLY GR/EP
BASELINE ENVIRONMENT, UNIT E-9, 12/9/77 TO 6/13/78



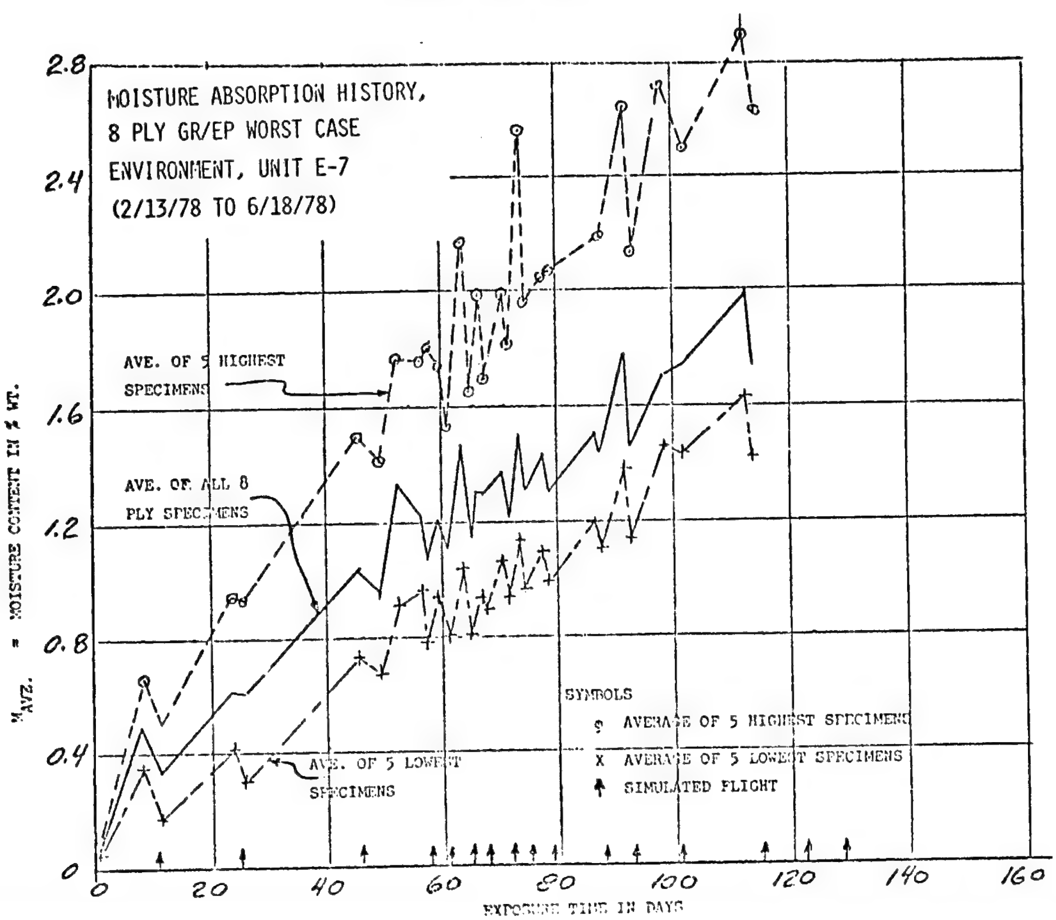
PREDICTION UNDER TEST ENVIRONMENT VS. TEST DATA FOR 16 PLY GR/EP
WORST CASE ENVIRONMENT, UNIT E-7, 2/13/73 TO 6/8/73





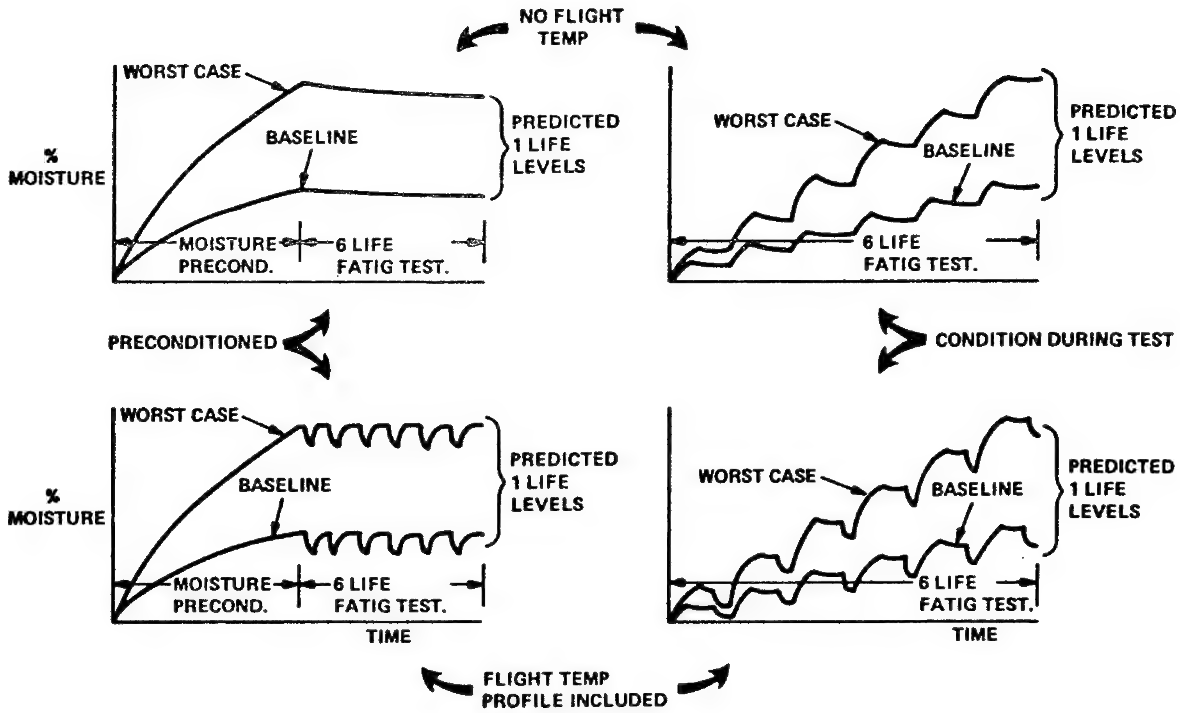


PREDICTION UNDER TEST ENVIRONMENT VS. TEST DATA FOR 8 PLY GR/EP,
WORST CASE ENVIRONMENT, UNIT E-7, 2/13/73 TO 6/8/78
AVERAGE OF TEST DATA
ANALYTICAL PREDICTION
SYMBOLS
SIMULATED FLIGHTS
M_{AVE} = MOISTURE CONTENT IN % WT.
EXPOSURE TIME IN DAYS



MOISTURE ABSORPTION HISTORY,
8 PLY GR/EP WORST CASE
ENVIRONMENT, UNIT E-7
(2/13/78 TO 6/18/78)
AVE. OF 5 HIGHEST SPECIMENS
AVE. OF ALL 8 PLY SPECIMENS
AVE. OF 5 LOWEST SPECIMENS
SYMBOLS
AVERAGE OF 5 HIGHEST SPECIMENS
X AVERAGE OF 5 LOWEST SPECIMENS
SIMULATED FLIGHT
$M_{AVE.}$ = MOISTURE CONTENT IN % WT.
EXPOSURE TIME IN DAYS

TASK III ACCELERATED TESTING



CONCLUSIONS

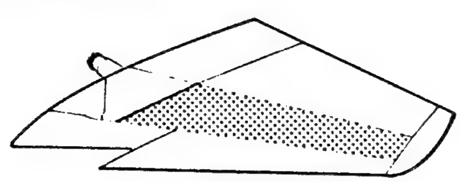
- RUNWAY STORAGE MODELS DEFINED
- TARGET MOISTURE LEVELS PREDICTED
- STATIC STRENGTH CHARACTERIZATION COMPLETED
- DIFFUSION ANOMALIES RAISE QUESTIONS ABOUT LONG TERM PREDICTIONS
- LAB AMBIENT FATIGUE IN PROGRESS
- REAL-TIME TESTS UNDERWAY
- UNIQUE TEST FACILITY IN OPERATION

EFFECT OF SERVICE ENVIRONMENT ON F-15 BORON/EPOXY STABILATOR

AFFDL CONTRACT F33615-77-C-3124

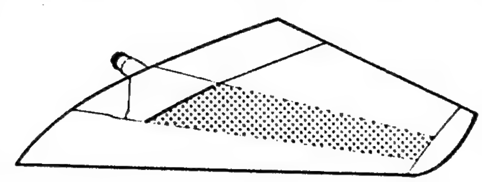
TOM HINKLE
MCDONNELL AIRCRAFT COMPANY
ST. LOUIS, MO

PRODUCTION STABILATOR EAGLE 14



DOCUMENTED ENVIRONMENTS FROM CLIMATIC TEST PROGRAM

REFURBISHED TEST ARTICLE PDV

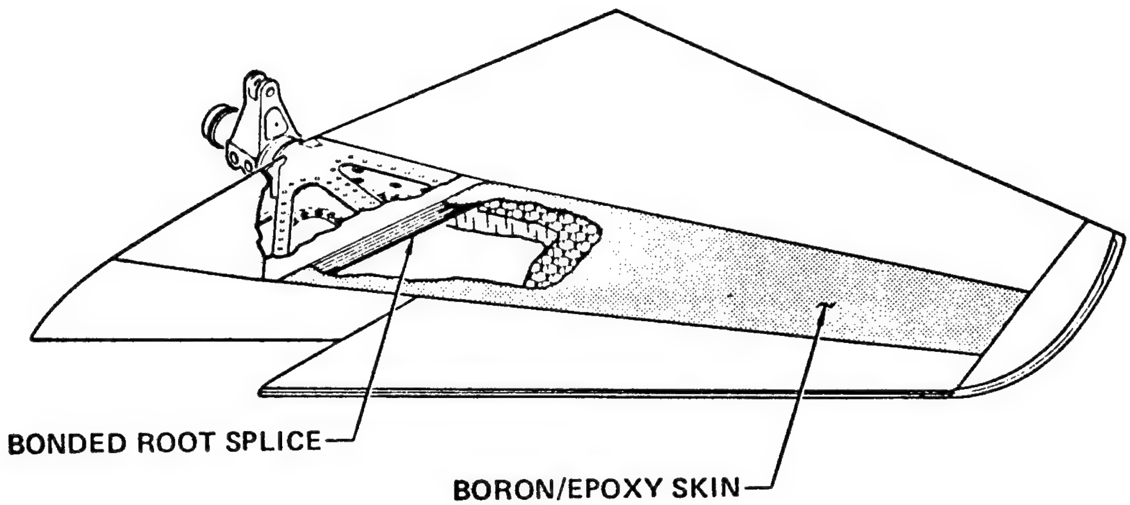


FATIGUE AND STATIC TESTS, LONG STORAGE PERIODS

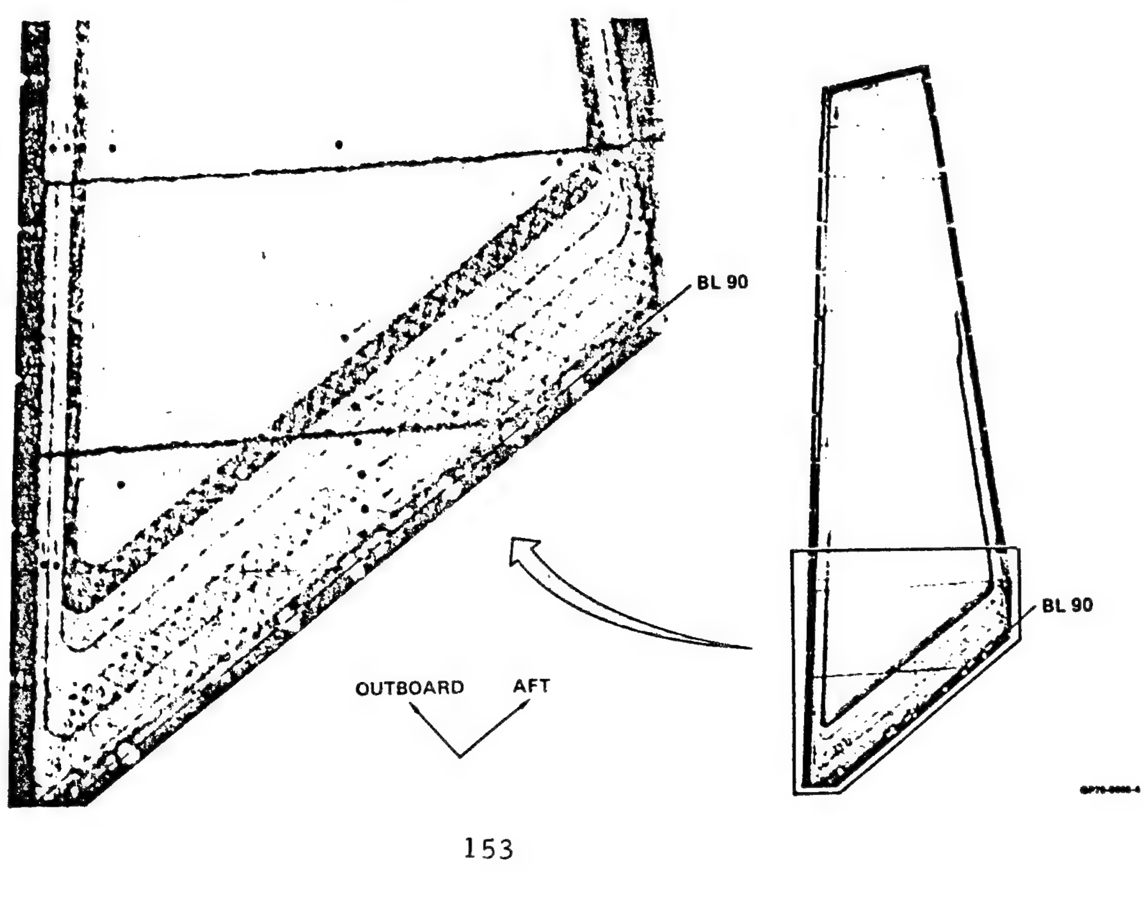
- NONDESTRUCTIVE EVALUATION AND COMPARISON WITH PRODUCTION RECORDS
- TWO FULL-SCALE STATIC TESTS AND COMPARISON OF RESULTS WITH DESIGN VERIFICATION TEST RESULTS
- TEST OF COUPONS MACHINED FROM STABILATOR COMPOSITE SKINS TO DETERMINE PHYSICAL AND MECHANICAL PROPERTIES
- CALCULATION OF MOISTURE-TIME PROFILES FOR VARIOUS F-15 DEPLOYMENTS

GP78-0968-2

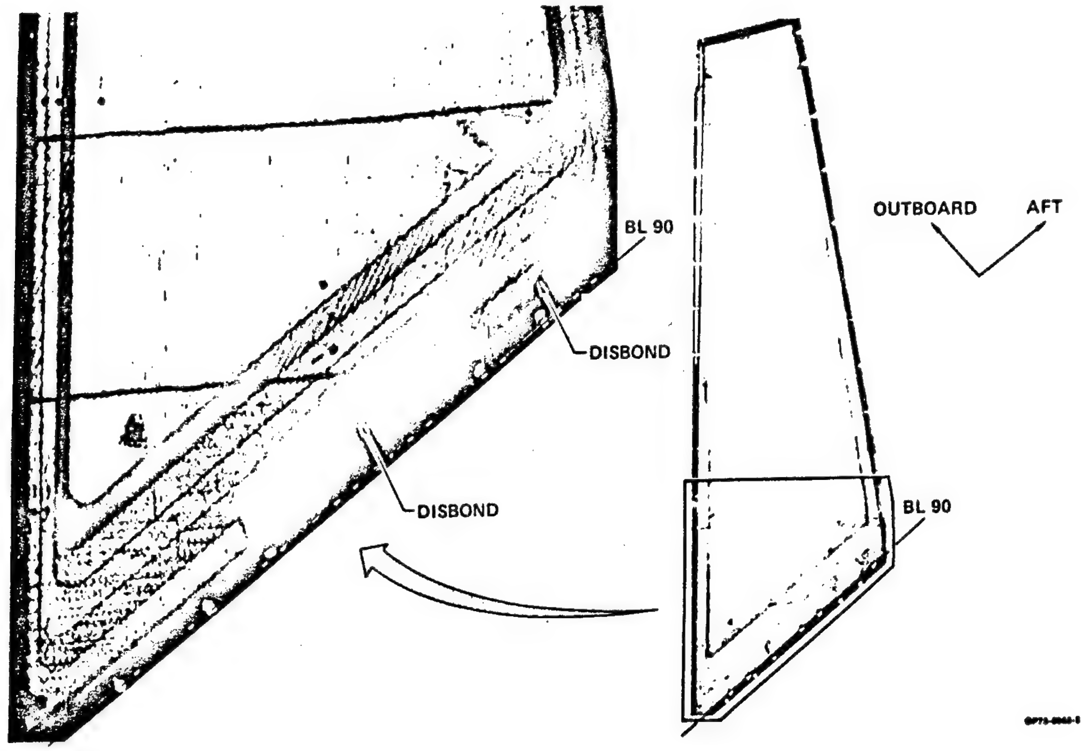
F-15 HORIZONTAL STABILATOR



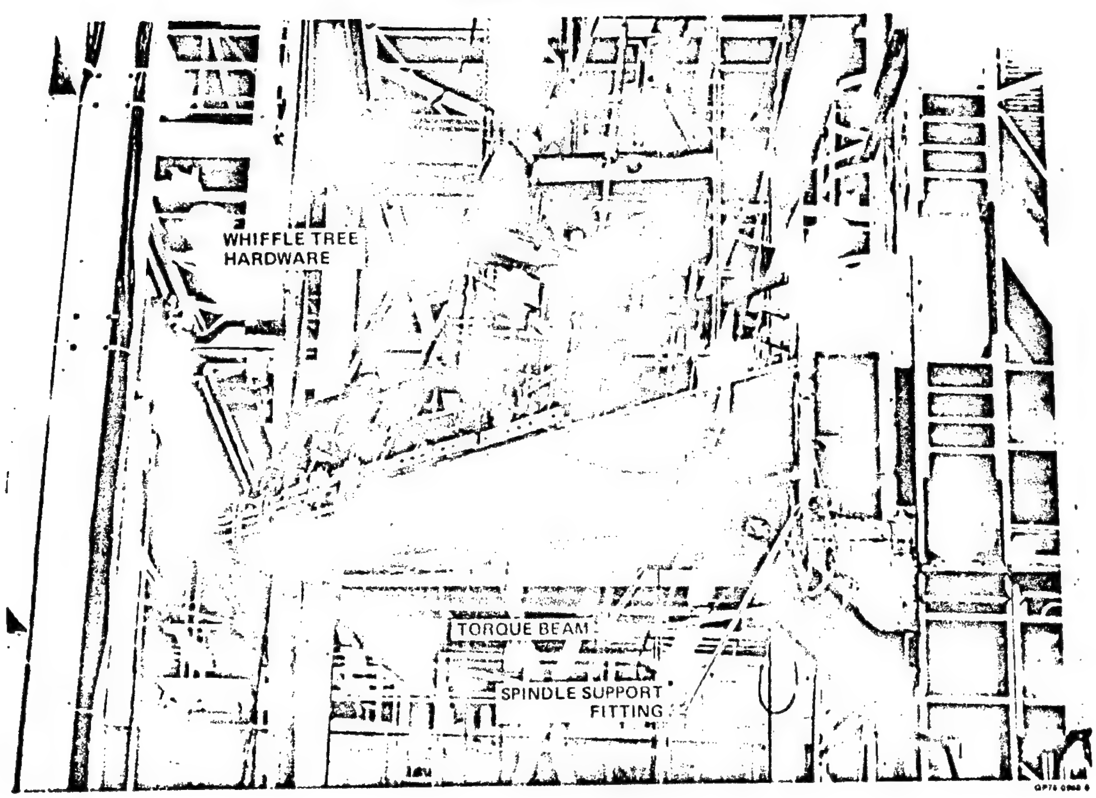
C-SCAN OF EAGLE 14 TORQUE BOX
NO DEFECTS IN ROOT SPLICE



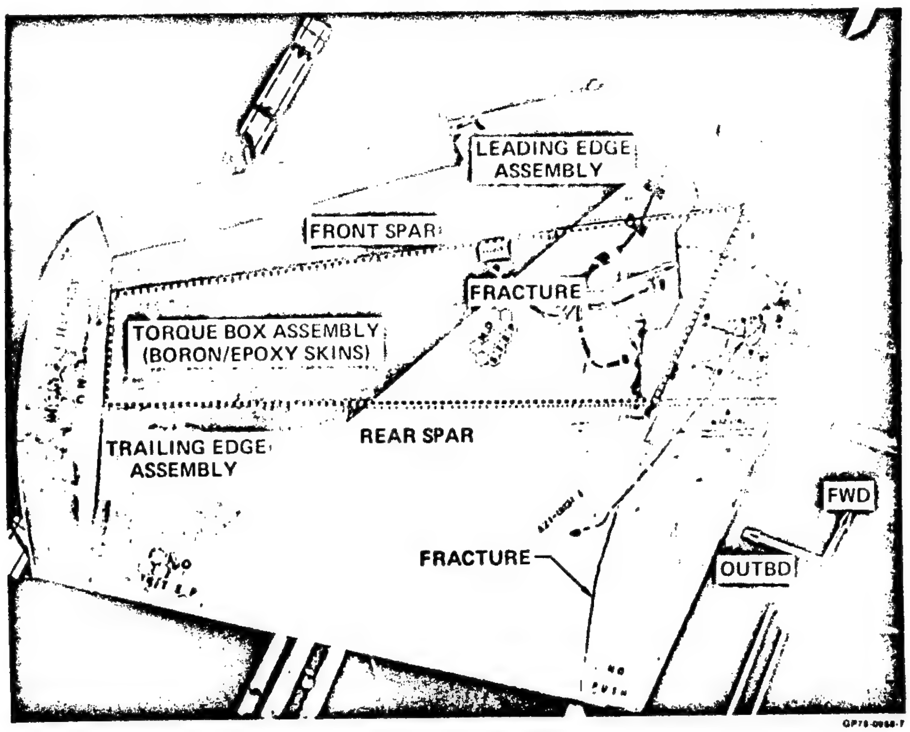
C-SCAN OF PDV TORQUE BOX
DISBONDS DETECTED IN ROOT SPLICE



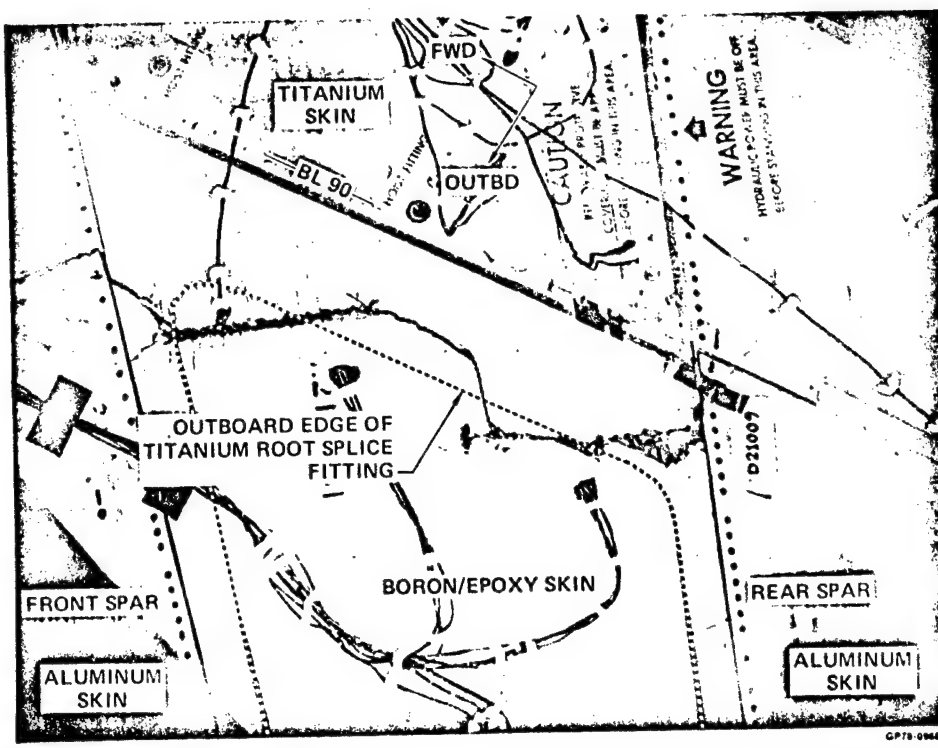
TEST SETUP



TENSION SKIN OF EAGLE 14 TEST ARTICLE
SIMILAR FAILURE MODE FOR PDV TEST ARTICLE



EAGLE 14 - ROOT SPLICE



TEST DATA CORRELATION

DATA MEASURED AT 150 PERCENT DLL	EAGLE 14 TEST	PDV TEST	DESIGN VERIFICATION TEST
STRAIN IN REAR SPAR CAP AT ROOT SPLICE	3492 μIN./IN.	3364 μIN./IN.	3400 μIN./IN.
PRINCIPAL STRAIN AT TIP OF SPLICE PLATE	2927 μIN./IN.	2800 μIN./IN.	2750 μIN./IN.
PRINCIPAL STRAIN AT MIDSPAN	3348 μIN./IN.	3247 μIN./IN.	3039 μIN./IN.
TIP DISPLACEMENT	12.6 IN.	12.4 IN.	12.2 IN.

GP78-0968-9

PEAK RECORDED STRAINS EXCEED COMPARABLE STRAINS FROM DESIGN VERIFICATION TEST

MEASURED PARAMETER	EAGLE 14 TEST	PDV TEST	DESIGN VERIFICATION TEST
MAXIMUM LOAD LEVEL (% DLL)	190% (FAILURE)	184% (FAILURE)	200% (NO FAILURE)
STRAIN - REAR SPAR CAP	4605 μIN./IN.	4891 μIN./IN.	4500 μIN./IN.
PRINCIPAL STRAIN - SPLICE PLATE TIP	3733 μIN./IN.	3565 μIN./IN.	3600 μIN./IN.
PRINCIPAL STRAIN - MIDSPAN	4197 μIN./IN.	4075 μIN./IN.	4033 μIN./IN.

GP78-0968-10

EAGLE 14	PDV
ENVIRONMENTAL HISTORY	
• ASSEMBLY - AUG 1973	• ASSEMBLY - MAY 1971
• CLIMATIC TESTS	• VERIFICATION TESTS
– DESERT, – TROPICS, – ARCTIC: JUL 1974 THROUGH FEB 1976	• TOOLING CHECKS
• STORAGE AT MCAIR	• STORAGE AT MCAIR

MEASURED MOISTURE CONTENTS - JULY 1978
(PERCENT OF COUPON DRY WEIGHT, RESIN CONTENT 30%)

EAGLE 14		PDV
0.63%	14-PLY SKIN	0.65%
0.54%	24-PLY SKIN	0.55%
0.37%	38-PLY SKIN	0.38%

GP78-0968-11

RESIN EVALUATIONS

CURED RESIN SAMPLES

- EAGLE 14
- PDV
- NEW LAMINATE

PHYSICAL, CHEMICAL AND THERMAL CHARACTERISTICS

- RESIN CONTENT - ACID DIGESTION
- PYROLYSIS PRODUCTS - GC/MS ANALYSIS
- CHARACTERISTIC TEMPERATURES - DSC ANALYSIS
- WEIGHT LOSS/TEMPERATURE PROFILE - TGA

RESULTS

- NO DIFFERENCES

GP78-0968-12

STATUS

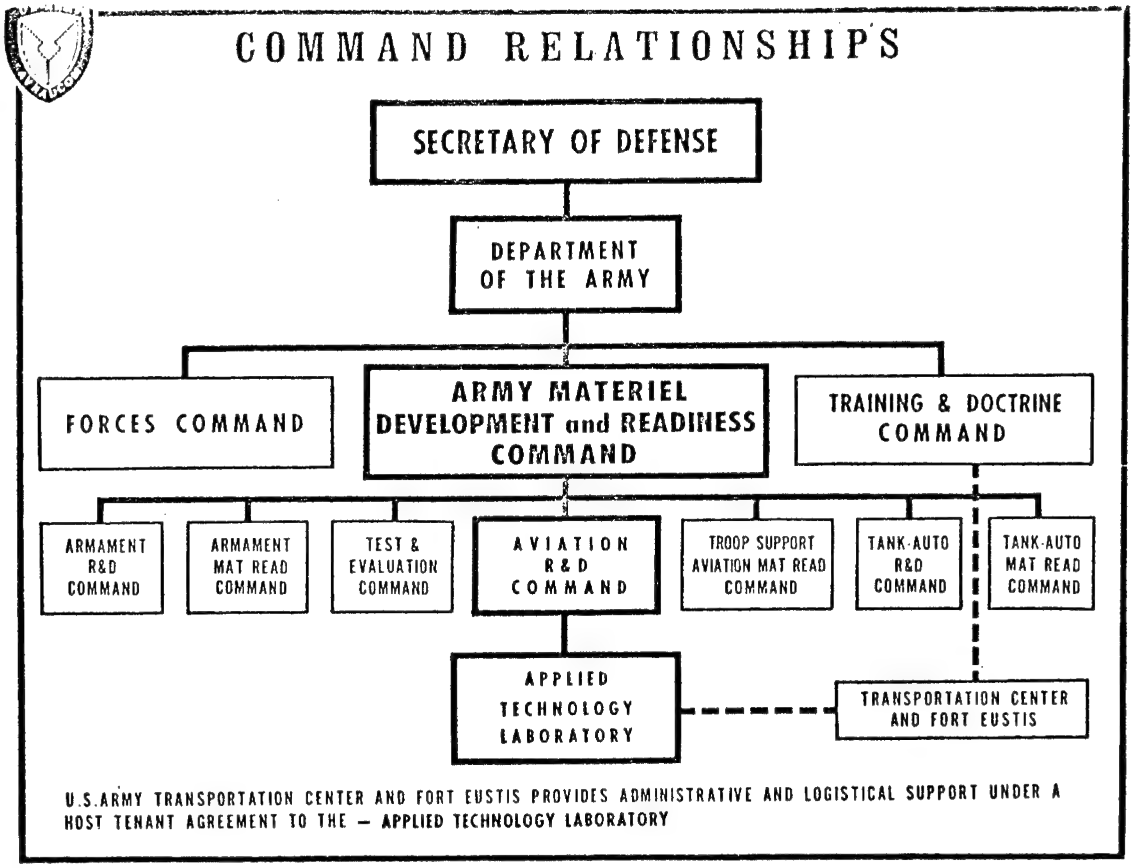
CONCLUSIONS

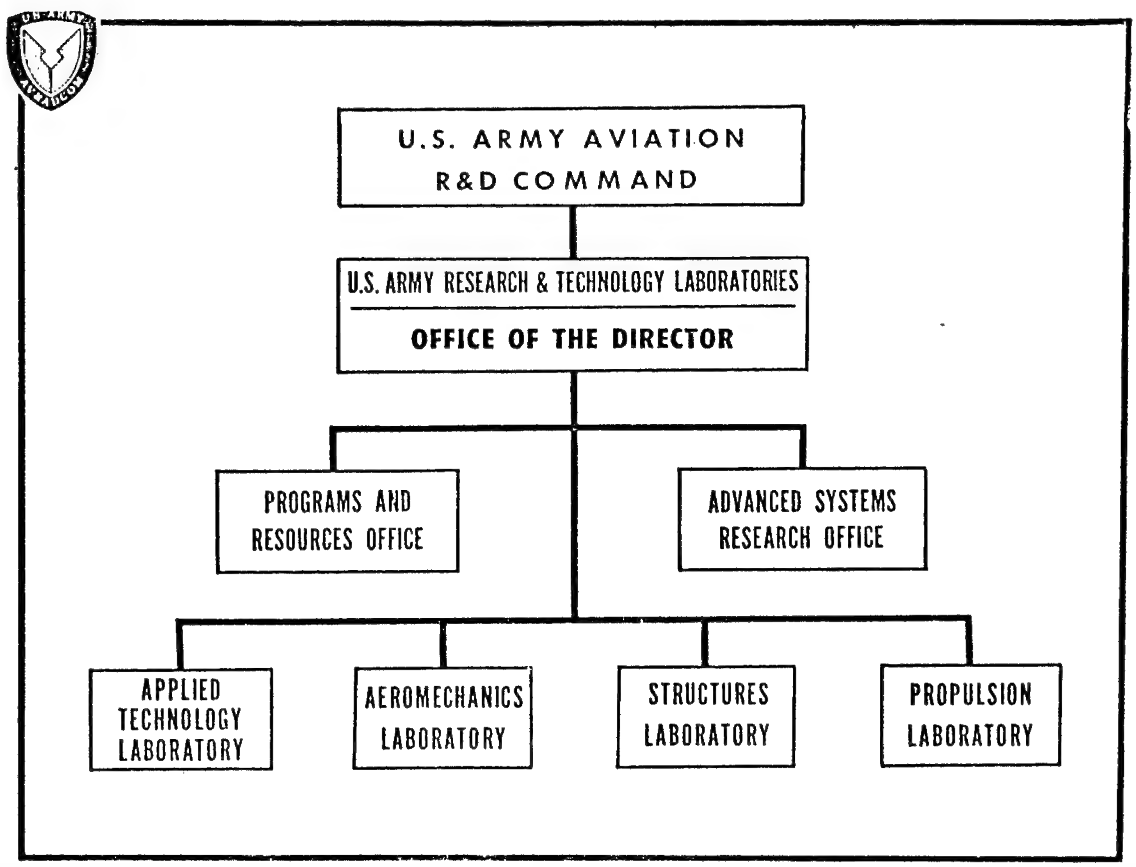
- NO STRUCTURAL DEGRADATION
- NO MATERIAL DEGRADATION

REMAINING WORK

- PREDICT MOISTURE CONTENTS USING "ENVIRONMENTAL SENSITIVITY" METHODOLOGY
- DETERMINE STRENGTH REDUCTION UNDER MAXIMUM EXPECTED MOISTURE CONTENT AND TEMPERATURE USING COUPON TESTS

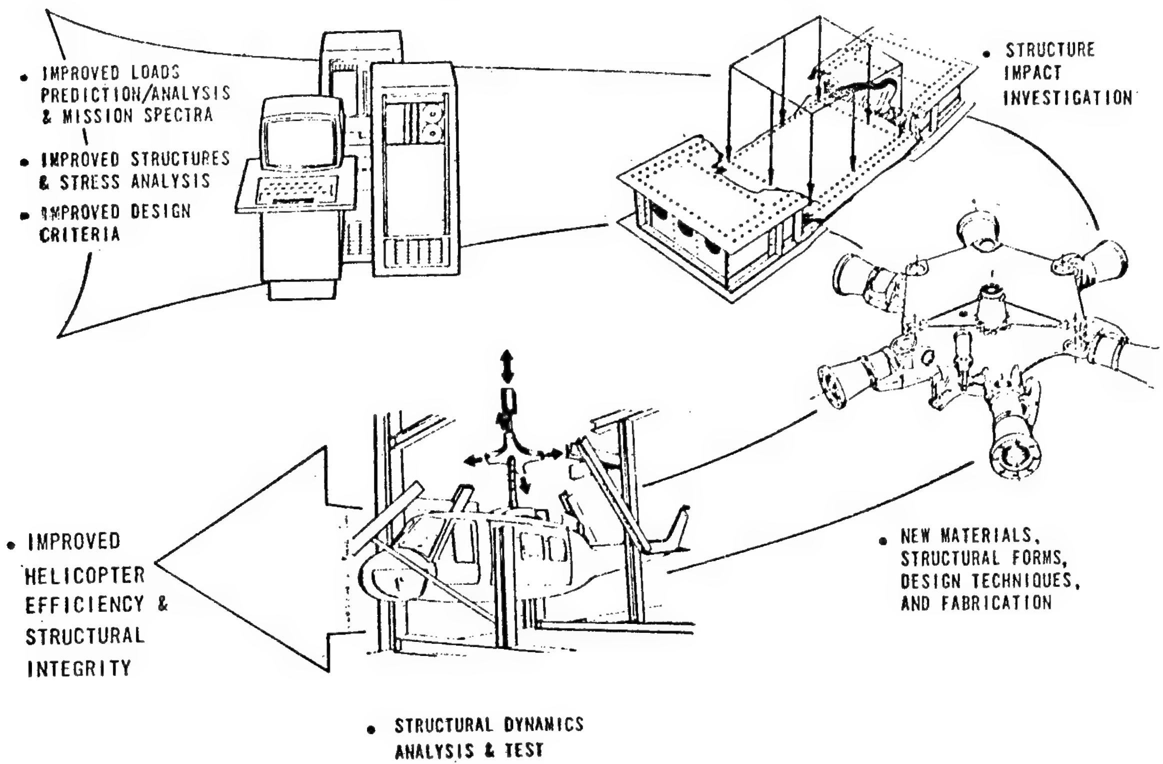
GP78–968-13


COMMAND RELATIONSHIPS
SECRETARY OF DEFENSE
DEPARTMENT OF THE ARMY
FORCES COMMAND
ARMY MATERIEL DEVELOPMENT and READINESS COMMAND
TRAINING & DOCTRINE COMMAND
ARMAMENT R&D COMMAND
ARMAMENT MAT READ COMMAND
TEST & EVALUATION COMMAND
AVIATION R & D COMMAND
TROOP SUPPORT AVIATION MAT READ COMMAND
TANK-AUTO R&D COMMAND
TANK-AUTO MAT READ COMMAND
APPLIED TECHNOLOGY LABORATORY
TRANSPORTATION CENTER AND FORT EUSTIS
U.S.ARMY TRANSPORTATION CENTER AND FORT EUSTIS PROVIDES ADMINISTRATIVE AND LOGISTICAL SUPPORT UNDER A HOST TENANT AGREEMENT TO THE — APPLIED TECHNOLOGY LABORATORY

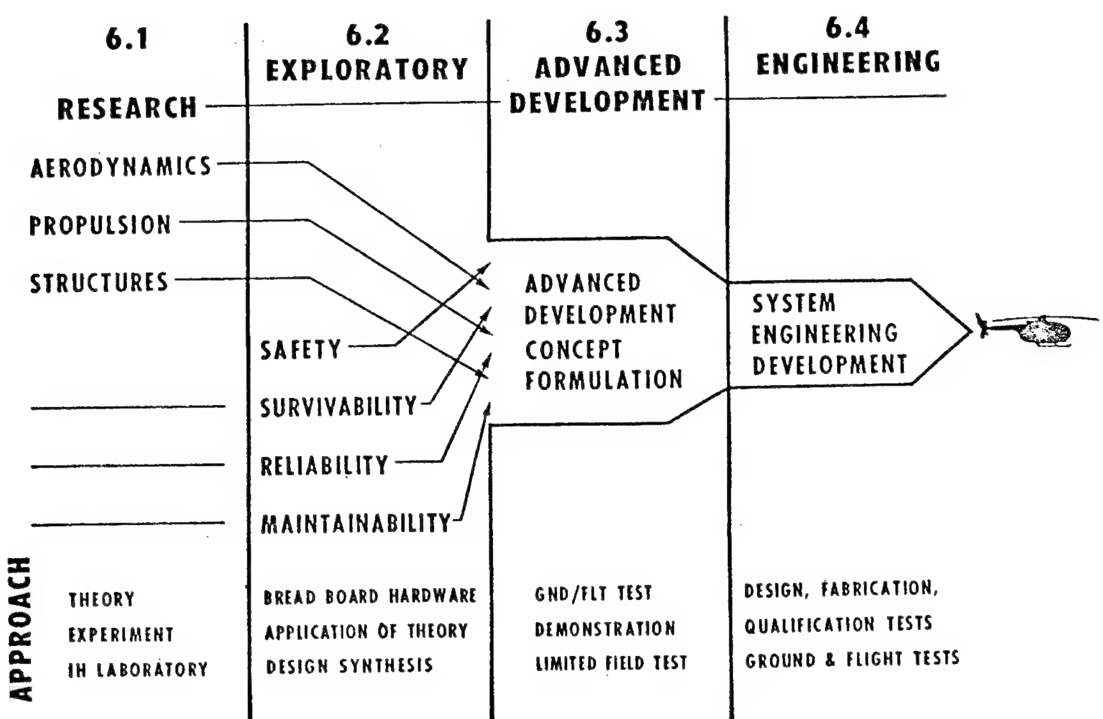

U.S. ARMY AVIATION R&D COMMAND
U.S. ARMY RESEARCH & TECHNOLOGY LABORATORIES
OFFICE OF THE DIRECTOR
PROGRAMS AND RESOURCES OFFICE
ADVANCED SYSTEMS RESEARCH OFFICE
APPLIED TECHNOLOGY LABORATORY
AEROMECHANICS LABORATORY
STRUCTURES LABORATORY
PROPULSION LABORATORY

STRESS & LOADS

(6.2 EXPLORATORY DEVELOPMENT)

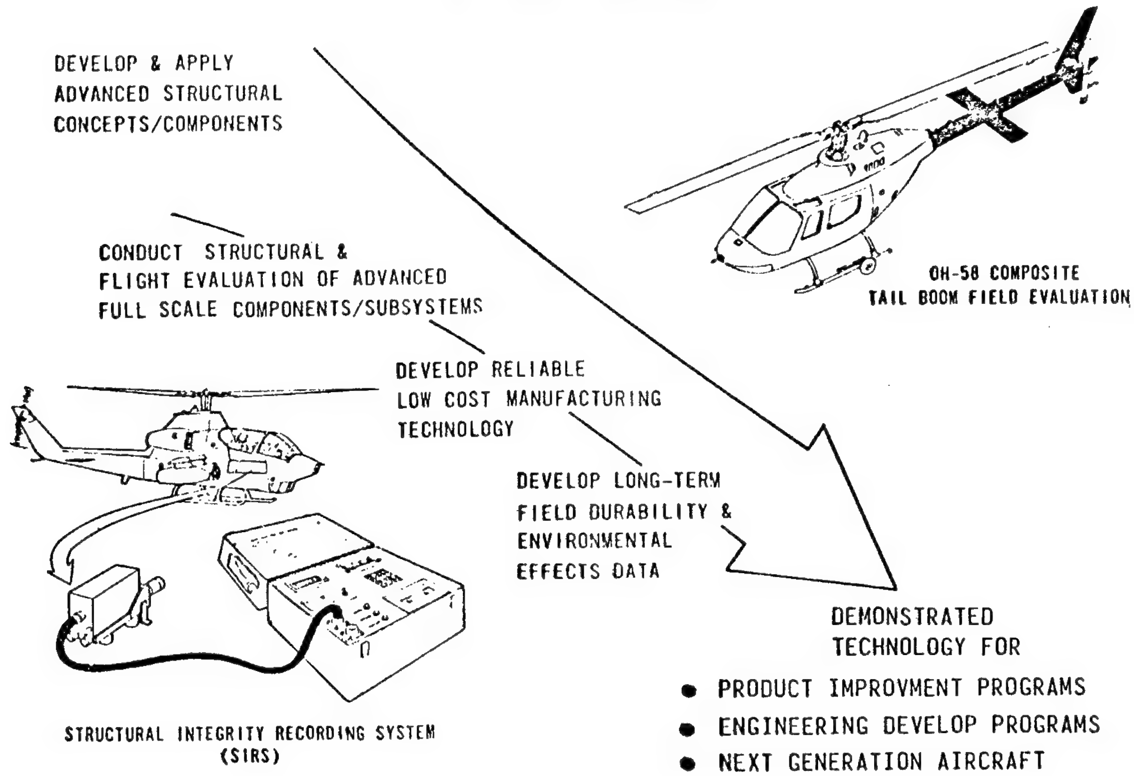


AIR MOBILITY R&D OVERVIEW

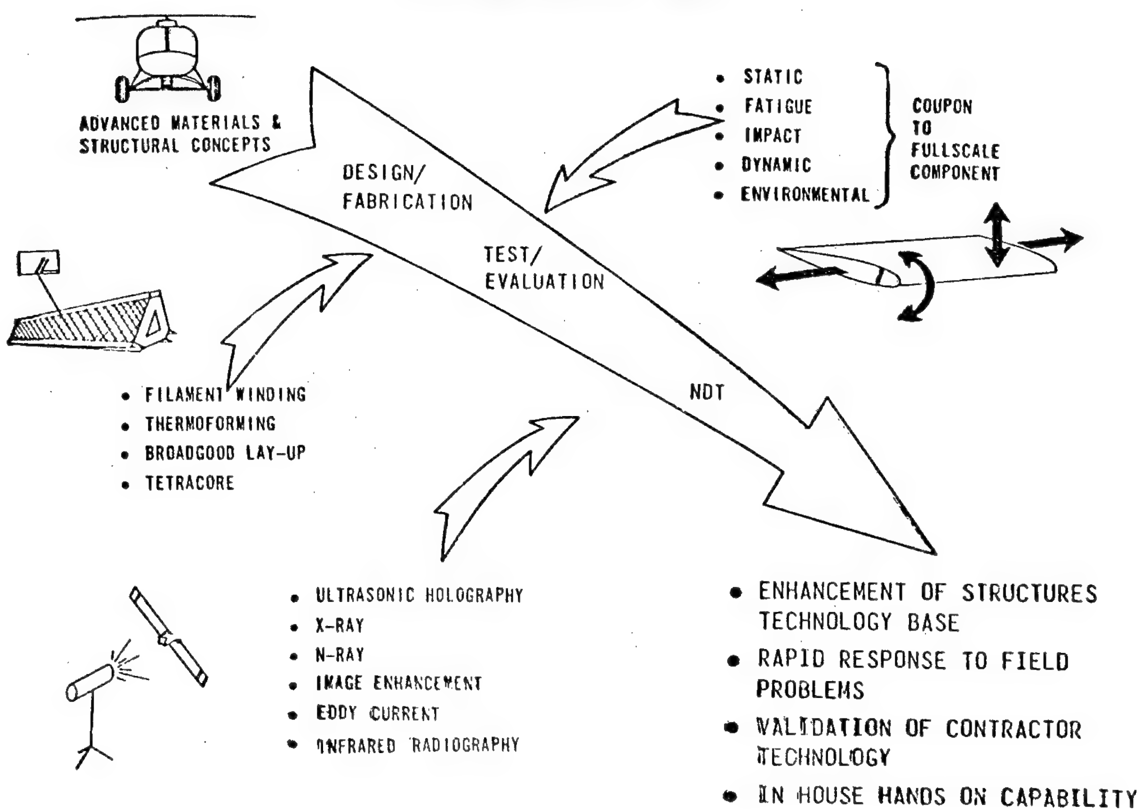


STRUCTURAL COMPONENTS

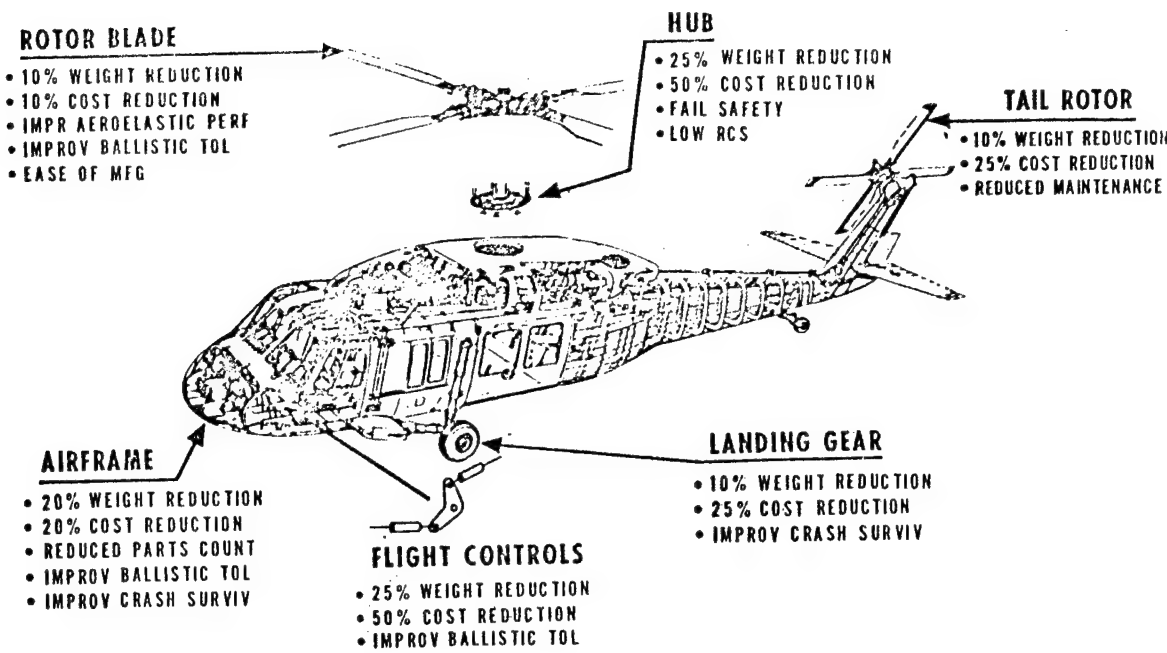
(6.3 ADVANCED DEVELOPMENT)



STRUCTURES LAB

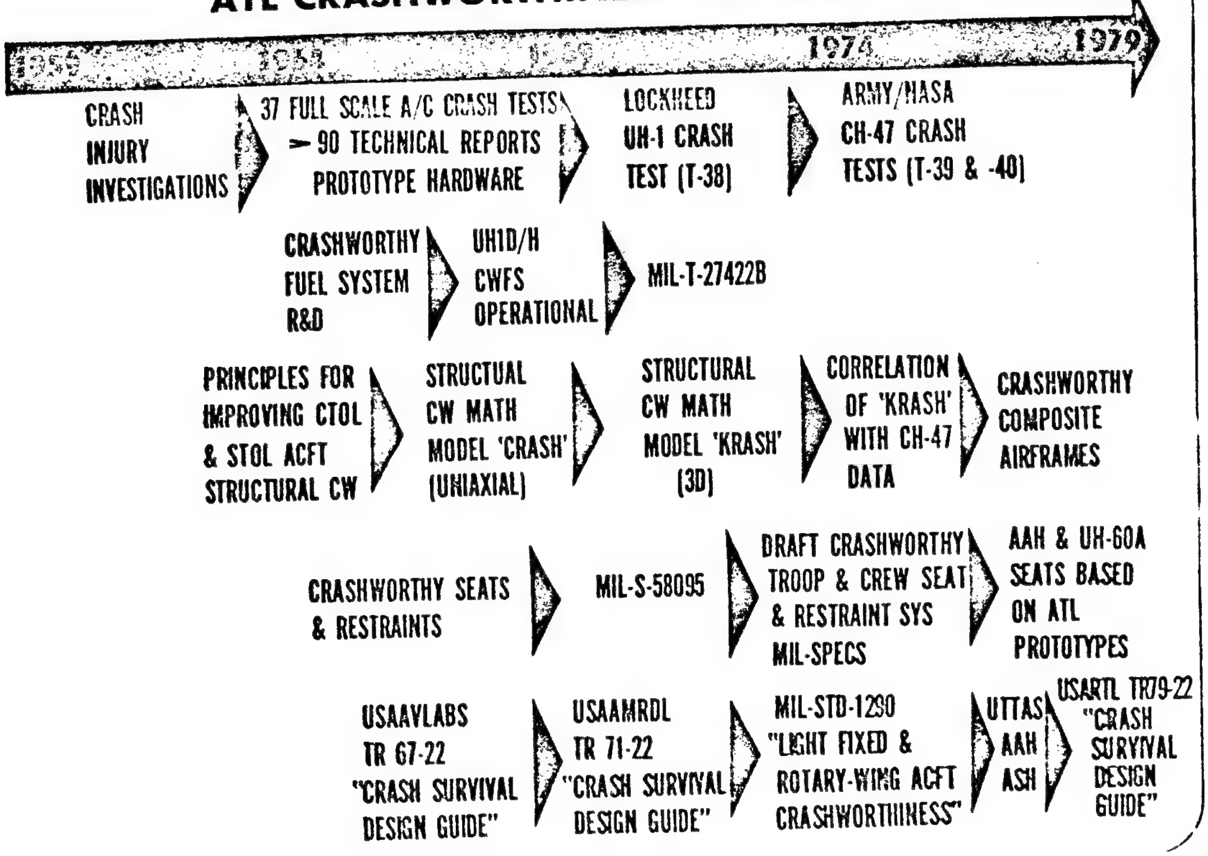


POTENTIAL COMPOSITES PROFITS



NOTE: % COST & WT REDUCTIONS REPRESENT THOSE VALUES OBTAINABLE IF ITEM IS HIGHEST PRIORITY

ATL CRASHWORTHINESS R&D PROGRESS



ADVANCED CONCEPTS FOR COMPOSITE STRUCTURE JOINTS AND ATTACHMENT FITTINGS PROGRAM

DAAJ02-77-C-0076

This briefing covers the analytical work accomplished under the Composite Joints and Fittings Program.

This program is sponsored by the Applied Technology Laboratory (ATL) of the U. S. Army Research and Development Command, Fort Eustis, Virginia, under Contract DAAJ02-77-C-0076

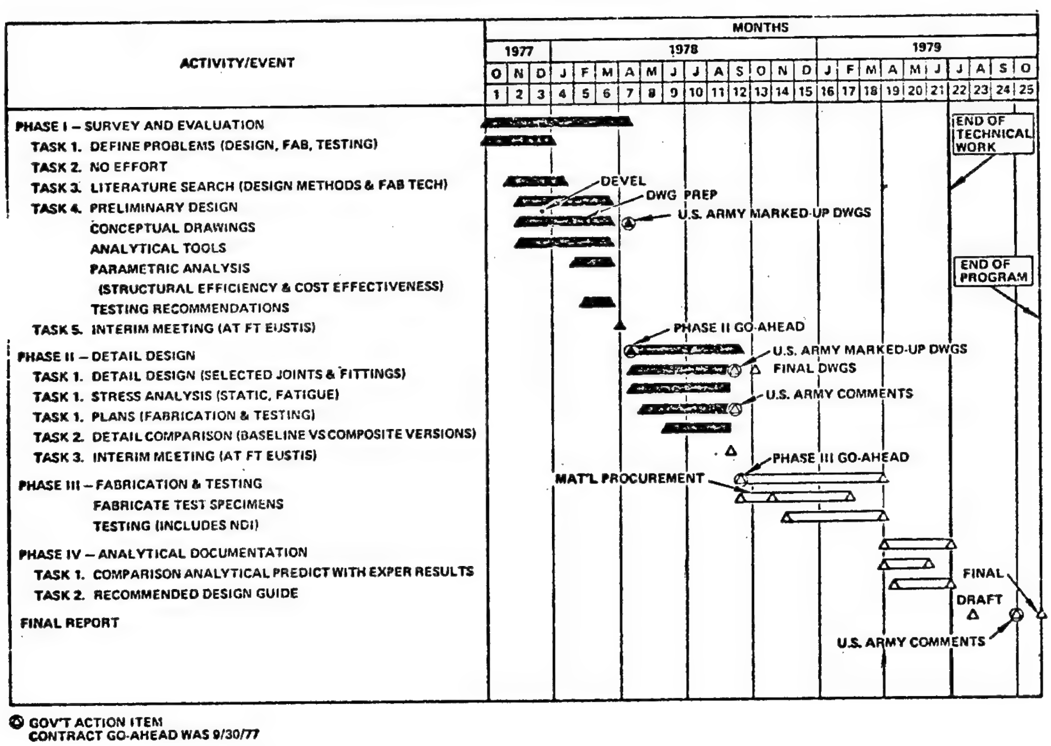
COMPOSITE JOINTS AND ATTACHMENT FITTINGS

AGENDA

- o BRIEF PROGRAM SUMMARY
- o ANALYTICAL METHODS USED

COMPOSITE JOINTS AND ATTACHMENT FITTINGS
PROGRAM SUMMARY

PROGRAM SCHEDULE



GOV'T ACTION ITEM
CONTRACT GO-AHEAD WAS 9/30/77

This program is divided into four phases:

I Preliminary Design

II Detail Design

III Fabrication and Test of 16 specimens covering three joint/fitting designs

IV Documentation

The program is scheduled for 25 months with 21 months of technical effort and 4 months for final report preparation, approval and release.

The program commenced on 30 September 1977 and will end in October 1979.

We are currently awaiting release of Phase III.

COMPOSITE JOINTS AND ATTACHMENT FITTINGS PROGRAM SUMMARY

OBJECTIVE

- Develop Competitive Basic Concepts
- Helicopter Primary Joints & Fittings
- Capable of Disassembly
- Cost Effective
- Save Weight

The program objective is to develop competitive basic concepts for helicopter primary joints and fittings capable of disassembly using composite materials which when integrated into composite components are cost effective and save weight when compared to the baseline metallic component.

COMPOSITE JOINTS AND FITTINGS
ANGLE BRACKET

ANALYTICAL METHODS USED

- o PRESENT STATE-OF-THE-ART CONVENTIONAL ANALYTICAL METHODS
- o THE ANGLE BRACKET INTERLAMINAR STRESS ANALYSIS

- ANGLE BRACKET - INTERLAMINAR STRESS ANALYSIS
  - PROBLEM DEFINITION
  - METHODS
  - COMPARATIVE ANALYSIS
  - OBSERVATIONS

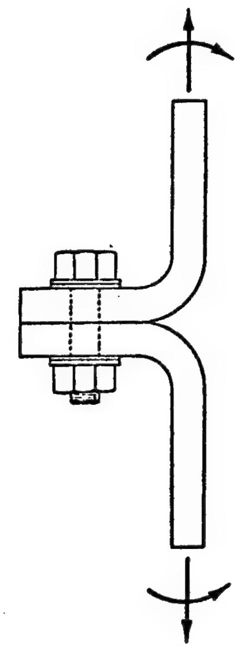
Hughes Helicopters

One of the problems that warranted attention is the laminated corner of tension joints.

PROBLEM DEFINITION

- TYPICAL CORNER BRACKET TENSION JOINT

- NATURE OF THE PROBLEM — EXISTING DISCONTINUITIES
  - (a) TENSION JOINT
  - (b) THE CORNER - PREMATURE DELAMINATIONS
  - (c) MATERIAL - ANISOTROPIC
    - HETROGENEOUS
    - LAMINATED



COMPOSITE JOINTS AND FITTINGS

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ASSUMPTIONS

- ENVIRONMENTAL EFFECTS ARE IGNORED
- MATERIAL IS HOMOGENEOUS, ORTHOTROPIC IN LOAD AXIS, WITH MATRIX ELASTIC PROPERTIES IN THE LATERAL DIRECTION
- LOAD IS UNIFORMLY DISTRIBUTED.

OBJECTIVE

- TO ESTABLISH METHODOLOGY FOR THE DETERMINATION OF INTERLAMINAR STRESSES

COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

ANALYTICAL METHODS

- THEORETICAL - THE FINITE DIFFERENCE SCHEME
- THE FINITE ELEMENT SCHEME - NASTRAN

COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

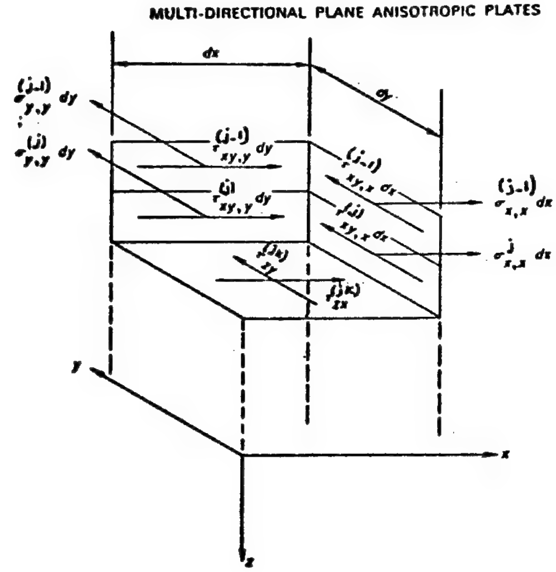
THEORETICAL

INTERLAMINAR SHEARING STRESS
LAMINAS J AND K

$$\tau_{zx}^{(jk)}\,dx\,dy = -\int_{h_0}^{h_j}\left(\sigma_{x,x}\,dx + \tau_{xy,y}\,dy\right)dz$$

$$\tau_{zy}^{(jk)}\,dx\,dy = -\int_{h_0}^{h_j}\left(\sigma_{y,y}\,dy + \tau_{xy,x}\,dx\right)dz$$

MULTI-DIRECTIONAL PLANE ANISOTROPIC PLATES



LAMINATED PLATE THEORY

$$[e^{(l)}] = \begin{bmatrix} e_{11}^{(l)} & e_{12}^{(l)} & e_{13}^{(l)} \\ e_{21}^{(l)} & e_{22}^{(l)} & e_{23}^{(l)} \\ e_{31}^{(l)} & e_{32}^{(l)} & e_{33}^{(l)} \end{bmatrix} = [C^{(l)}][a^{\cdot\cdot}]$$

$$[f^{(l)}] = \begin{bmatrix} f_{11}^{(l)} & f_{12}^{(l)} & f_{13}^{(l)} \\ f_{21}^{(l)} & f_{22}^{(l)} & f_{23}^{(l)} \\ f_{31}^{(l)} & f_{32}^{(l)} & f_{33}^{(l)} \end{bmatrix} = [C^{(l)}][b^{\cdot\cdot}]$$

$$[g^{(l)}] = \int_{h_{l-1}}^{h_l} [e^{(l)}]\,dz = (h_l - h_{l-1})[e^{(l)}]$$

$$[h^{(l)}] = \int_{h_{l-1}}^{h_l} [f^{(l)}]\,dz = (h_l - h_{l-1})[f^{(l)}]$$

$$[p^{(l)}] = \int_{h_{l-1}}^{h_l} z[C^{(l)}]\,dz = \tfrac{1}{2}(h_l^2 - h_{l-1}^2)[C^{(l)}]$$

$$\tau_{xz}^{(N)} = -\sum_{l=1}^{J}\Big[\lfloor g_{11}^{(l)} \;\; g_{12}^{(l)} \;\; g_{13}^{(l)}\rfloor \begin{Bmatrix} U_{,yyx} \\ U_{,xxx} \\ -U_{,xyx} \end{Bmatrix}$$

$$+\lfloor h_{11}^{(l)} - p_{11}^{(l)} \;\; h_{12}^{(l)} - p_{12}^{(l)} \;\; h_{13}^{(l)} - p_{13}^{(l)}\rfloor \begin{Bmatrix} w_{,xxx} \\ w_{,yyx} \\ 2w_{,xyx} \end{Bmatrix}$$

$$+\lfloor g_{31}^{(l)} \;\; g_{32}^{(l)} \;\; g_{33}^{(l)}\rfloor \begin{Bmatrix} U_{,yyy} \\ U_{,xxy} \\ -U_{,xyy} \end{Bmatrix}$$

$$+\lfloor h_{31}^{(l)} - p_{13}^{(l)} \;\; h_{32}^{(l)} - p_{23}^{(l)} \;\; h_{33}^{(l)} - p_{33}^{(l)}\rfloor \begin{Bmatrix} w_{,xxy} \\ w_{,yyy} \\ 2w_{,xyy} \end{Bmatrix}\Big]$$

In a similar manner

$$\tau_{yz}^{(N)} = -\sum_{l=1}^{J}\Big[\lfloor g_{21}^{(l)} \;\; g_{22}^{(l)} \;\; g_{23}^{(l)}\rfloor \begin{Bmatrix} U_{,yyy} \\ U_{,xxy} \\ -U_{,xyy} \end{Bmatrix}$$

$$+\lfloor h_{21}^{(l)} - p_{12}^{(l)} \;\; h_{22}^{(l)} - p_{22}^{(l)} \;\; h_{23}^{(l)} - p_{23}^{(l)}\rfloor \begin{Bmatrix} w_{,xxy} \\ w_{,yyy} \\ 2w_{,xyy} \end{Bmatrix}$$

$$+\lfloor g_{31}^{(l)} \;\; g_{32}^{(l)} \;\; g_{33}^{(l)}\rfloor \begin{Bmatrix} U_{,yyx} \\ U_{,xxx} \\ -U_{,xyx} \end{Bmatrix}$$

$$+\lfloor h_{31}^{(l)} - p_{13}^{(l)} \;\; h_{32}^{(l)} - p_{23}^{(l)} \;\; h_{33}^{(l)} - p_{33}^{(l)}\rfloor \begin{Bmatrix} w_{,xxx} \\ w_{,yyx} \\ 2w_{,xyx} \end{Bmatrix}\Big]$$

COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

LAMINATED CYLINDRICAL SHELL THEORY

$$\tau_{xz}^{(N)} = -\sum_{l=1}^{J}\Big[\lfloor g_{11}^{(l)} \;\; g_{12}^{(l)} \;\; g_{13}^{(l)}\rfloor \begin{Bmatrix} \dfrac{U_{,\theta\theta x}}{r^2} \\ U_{,xxx} \\ -\dfrac{U_{,x\theta x}}{r} \end{Bmatrix}$$

$$+\lfloor h_{11}^{(l)} - p_{11}^{(l)} \;\; h_{12}^{(l)} - p_{12}^{(l)} \;\; h_{13}^{(l)} - p_{13}^{(l)}\rfloor \begin{Bmatrix} w_{0,xxx} \\ \dfrac{w_{0,\theta\theta x}}{r^2} \\ \dfrac{2w_{0,x\theta x}}{r} \end{Bmatrix} + \lfloor g_{31}^{(l)} \;\; g_{32}^{(l)} \;\; g_{33}^{(l)}\rfloor \begin{Bmatrix} \dfrac{U_{,\theta\theta\theta}}{r^3} \\ \dfrac{U_{,xx\theta}}{r} \\ -\dfrac{U_{,x\theta\theta}}{r^2} \end{Bmatrix}$$

$$+\lfloor h_{31}^{(l)} - p_{13}^{(l)} \;\; h_{32}^{(l)} - p_{23}^{(l)} \;\; h_{33}^{(l)} - p_{33}^{(l)}\rfloor \begin{Bmatrix} \dfrac{w_{0,xx\theta}}{r} \\ \dfrac{w_{0,\theta\theta\theta}}{r^3} \\ \dfrac{2w_{0,x\theta\theta}}{r^2} \end{Bmatrix}\Big]$$

and

$$\tau_{\theta z}^{(N)} = -\sum_{l=1}^{J}\Big[\lfloor g_{21}^{(l)} \;\; g_{22}^{(l)} \;\; g_{23}^{(l)}\rfloor \begin{Bmatrix} \dfrac{U_{,\theta\theta\theta}}{r^3} \\ \dfrac{U_{,xx\theta}}{r} \\ -\dfrac{U_{,x\theta\theta}}{r^2} \end{Bmatrix}$$

$$+\lfloor h_{21}^{(l)} - p_{12}^{(l)} \;\; h_{22}^{(l)} - p_{22}^{(l)} \;\; h_{23}^{(l)} - p_{23}^{(l)}\rfloor \begin{Bmatrix} \dfrac{w_{0,xx\theta}}{r} \\ \dfrac{w_{0,\theta\theta\theta}}{r^3} \\ \dfrac{2w_{0,x\theta\theta}}{r^2} \end{Bmatrix} + \lfloor g_{31}^{(l)} \;\; g_{32}^{(l)} \;\; g_{33}^{(l)}\rfloor \begin{Bmatrix} \dfrac{U_{,\theta\theta x}}{r^2} \\ U_{,xxx} \\ -\dfrac{U_{,x\theta x}}{r} \end{Bmatrix}$$

$$+\lfloor h_{31}^{(l)} - p_{13}^{(l)} \;\; h_{32}^{(l)} - p_{23}^{(l)} \;\; h_{33}^{(l)} - p_{33}^{(l)}\rfloor \begin{Bmatrix} w_{0,xxx} \\ \dfrac{w_{0,\theta\theta x}}{r^2} \\ \dfrac{2w_{0,x\theta x}}{r} \end{Bmatrix}\Big]$$

COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

INTERLAMINAR TENSION

BASED ON THE THICK PLATE THEORY

3-DIMENSIONAL ANISOTROPY ELASTIC PROPERTIES

$$\{\sigma\} = [\bar{C}_{ij}]\,\{\epsilon\}$$

$$\{\sigma\}^{(K)} = [\bar{C}_{ij}]^{(K)}\{\epsilon\}^{(K)} \quad K^{th}\ \text{LAMINA}$$

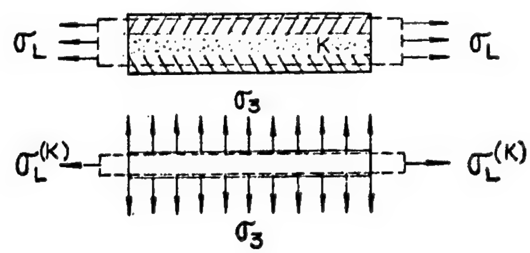
$$\text{BUT} \quad \{\epsilon\}^{(K)} = \{\epsilon\} = [\bar{S}_{ij}]\{\sigma\}$$

$$\text{WHERE: } [\bar{S}_{ij}] = [\bar{C}_{ij}]^{-1}$$

$$\therefore \{\sigma\}^{(K)} = [C_{ij}]^{(K)}[S_{ij}]\,\{\sigma\}$$

$[C_{ij}]$ = STIFFNESS MATRIX

$[S_{ij}]$ = COMPLIANCE MATRIX



$$\{\sigma\} = \begin{Bmatrix} \sigma_L \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix}$$

COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

FINITE ELEMENT

- PREPROCESSOR - MESH GENERATOR "GENGRID"
  - IDEALIZATION
  - PARAMETERS
  - ELEMENTS
- BOUNDARY CONDITIONS
- MATERIAL PROPERTIES
- APPLIED LOADS
- NASTRAN EXAMPLE

THE FINITE ELEMENT

a. MODEL C-l

AN IDEALIZATION OF THE ANGLE BRACKET TO STUDY THE INTERNAL DISPLACEMENT/LOAD DISTRIBUTION

b. MODEL C-2

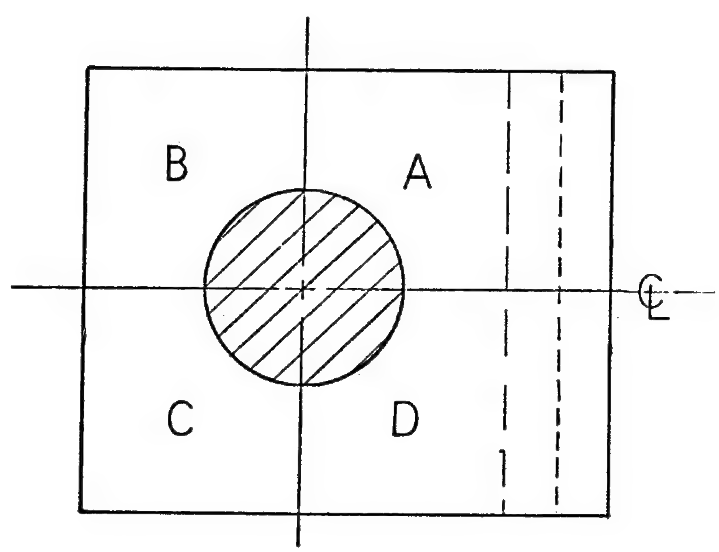
A "LAMINATED STRIP" TAKEN FROM C-1 TO DETERMINE THE INTERLAMINAR STRESS/STRAINS

COMPOSITE JOINTS AND FITTINGS

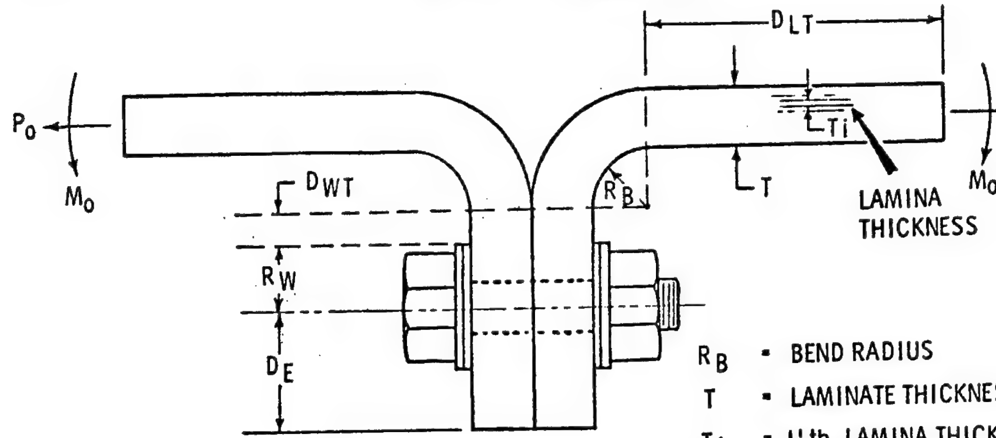
ANGLE BRACKET

IDEALIZATION

Symmetry
C & D are a Mirror Image
of B & A



DESIGN PARAMETERS



- R_B ▪ BEND RADIUS
- T ▪ LAMINATE THICKNESS
- T_i ▪ I'th LAMINA THICKNESS
- R_W ▪ WASHER RADIUS
- D_{WT} ▪ WASHER TO TANGENT LINE DISTAN
- D_{LT} ▪ LOAD TO TANGENT LINE DISTANCE
- D_E ▪ EDGE DISTANCE
- P_o ▪ APPLIED NORMAL LOAD
- M_o ▪ APPLIED BENDING MOMENT

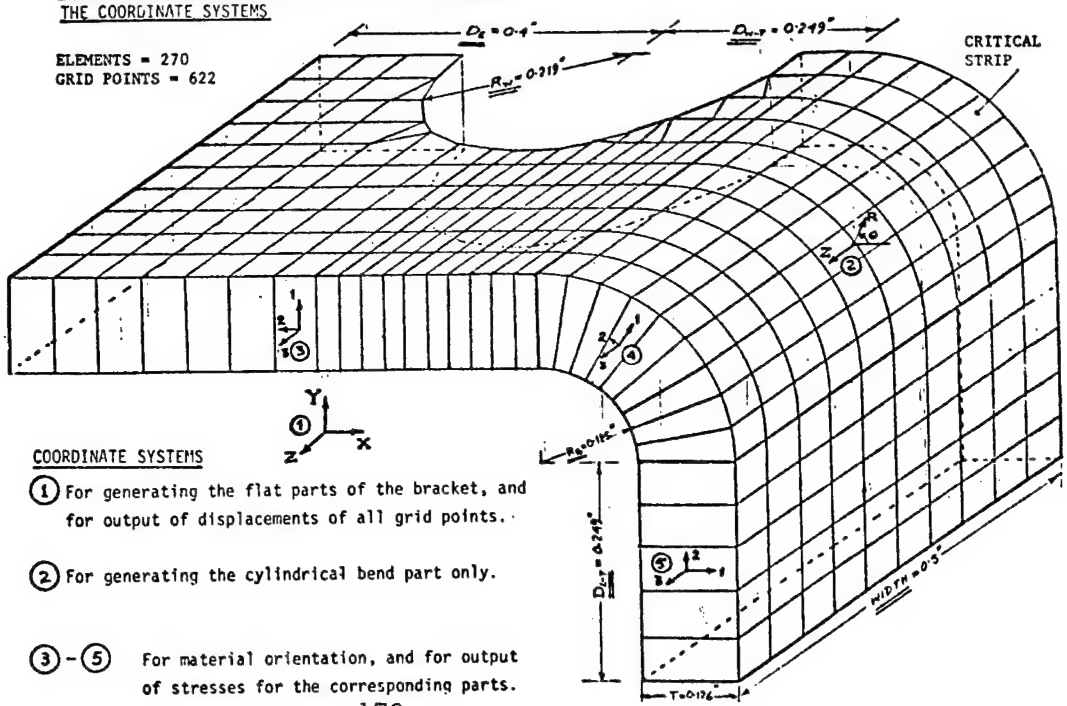
Hughes Helicopters

COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

PREPROCESSOR GENERATED NASTRAN MODEL (C1-0), AND THE COORDINATE SYSTEMS

ELEMENTS = 270
GRID POINTS = 622



COORDINATE SYSTEMS

(1) For generating the flat parts of the bracket, and for output of displacements of all grid points.

(2) For generating the cylindrical bend part only.

(3) - (5) For material orientation, and for output of stresses for the corresponding parts.

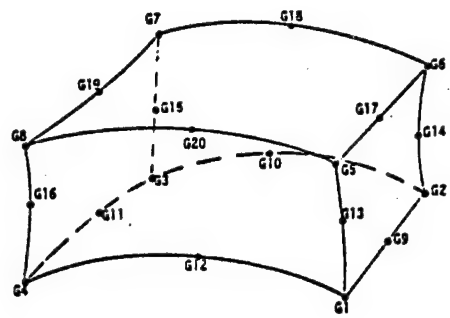
COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

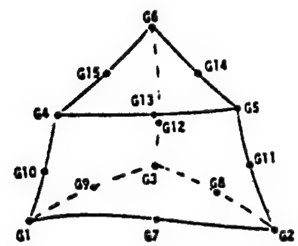
ISOPERAMETRIC ELEMENTS

"MSC/NASTRAN"

1. HEXA



2. PENTA



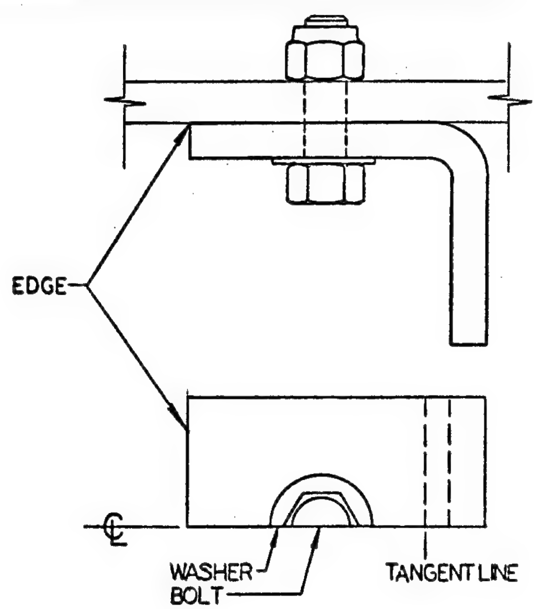
COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

BOUNDARY CONDITIONS (MODEL C-1)

Washer Boundary is Fixed

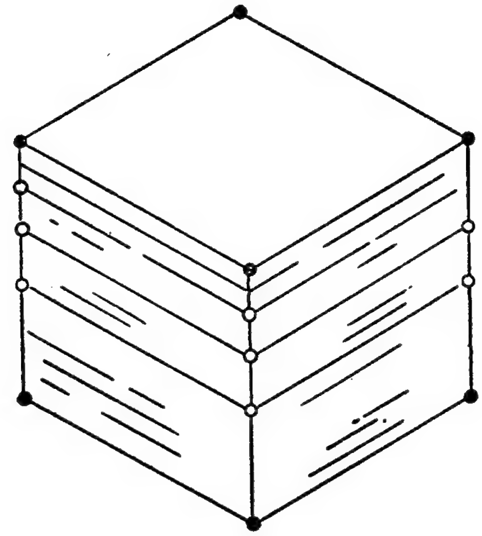
Edge Constrained Normally



COMPOSITE JOINTS & FITTINGS
ANGLE BRACKET

BOUNDRY CONDITIONS (MODEL C - 2)

- ● SINGLE POINT CONSTRAINTS & INFORCED DISPLACEMENTS – FOR GRIDS @ THE SURFACES AS IS IN THE C-1 OUTPUT
- ○ MULTIPOINT CONSTRAINTS (RSPLINE) - FOR THE INNER GRIDS (NEW GRIDS CREATED FOR C-2)



COMPOSITE JOINTS AND FITTINGS
ANGLE BRACKET

MATERIAL PROPERTIES

$$
[G_{ij}] = \begin{bmatrix}
\frac{(1-V_{23}V_{32})E_{11}}{V} & \frac{(V_{21}+V_{23}V_{31})E_{11}}{V} & \frac{(V_{31}+V_{21}V_{32})E_{11}}{V} & 0 & 0 & 0 \\
\frac{(V_{12}+V_{13}V_{32})E_{22}}{V} & \frac{(1-V_{31}V_{13})E_{22}}{V} & \frac{(V_{32}+V_{12}V_{31})E_{22}}{V} & 0 & 0 & 0 \\
\frac{(V_{13}+V_{23}V_{12})E_{33}}{V} & \frac{(V_{23}+V_{21}V_{13})E_{33}}{V} & \frac{(1-V_{12}V_{21})E_{33}}{V} & 0 & 0 & 0 \\
0 & 0 & 0 & G_{12} & 0 & 0 \\
0 & 0 & 0 & 0 & G_{23} & 0 \\
0 & 0 & 0 & 0 & 0 & G_{31}
\end{bmatrix}
$$

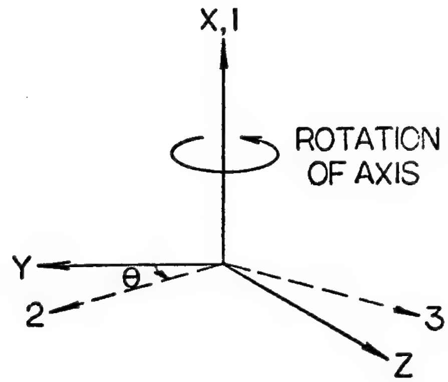
WHERE $\underline{V \quad 1 - V_{12}V_{21} - V_{23}V_{32} - V_{31}V_{13} - 2V_{12}V_{23}V_{31}}$

MATERIAL PROPERTIES

$$[G^{(K)}] = [T^{(K)}]^{-1}[G^{(K)}][T^{(K)}]$$

$$[T^{(K)}] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & M^2 & N^2 & 0 & 2MN & 0 \\ 0 & N^2 & M^2 & 0 & -2MN & 0 \\ 0 & 0 & 0 & M & 0 & -N \\ 0 & -MN & MN & 0 & M^2-N^2 & 0 \\ 0 & 0 & 0 & N & 0 & M \end{bmatrix}$$

WHERE:
$M = \cos\theta$
$N = \sin\theta$

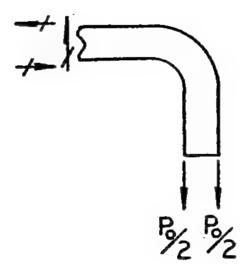


Hughes Helicopters

APPLIED LOADS

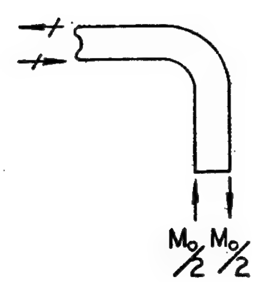
CASE 1

UNIFORMLY DISTRIBUTED PULL

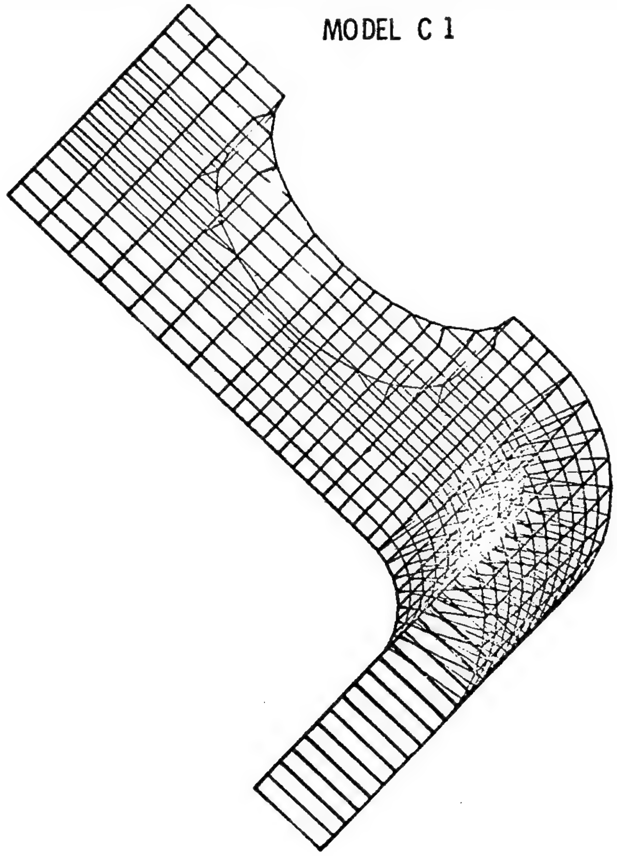


CASF 2

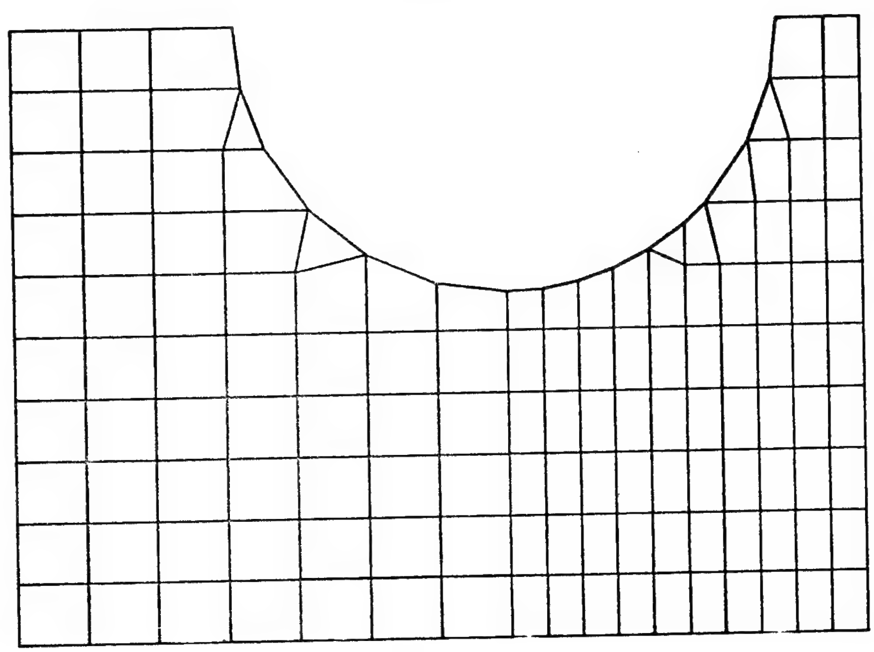
IN CASE OF AN INITIAL ECCENTRICITY
A COUPLE IS APLLIED UNIFORMLY
DISTRIBUTED ACROSS THE EDGES

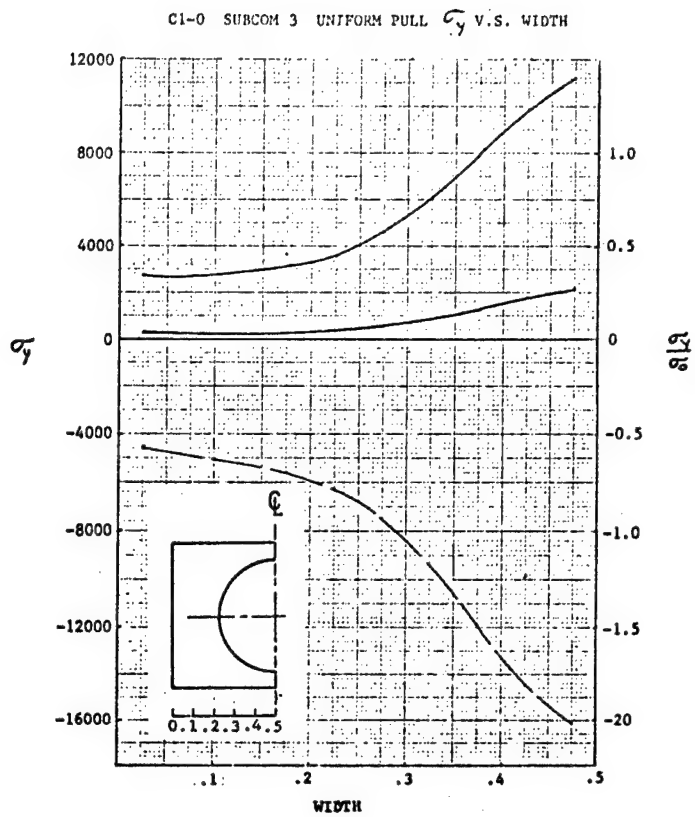


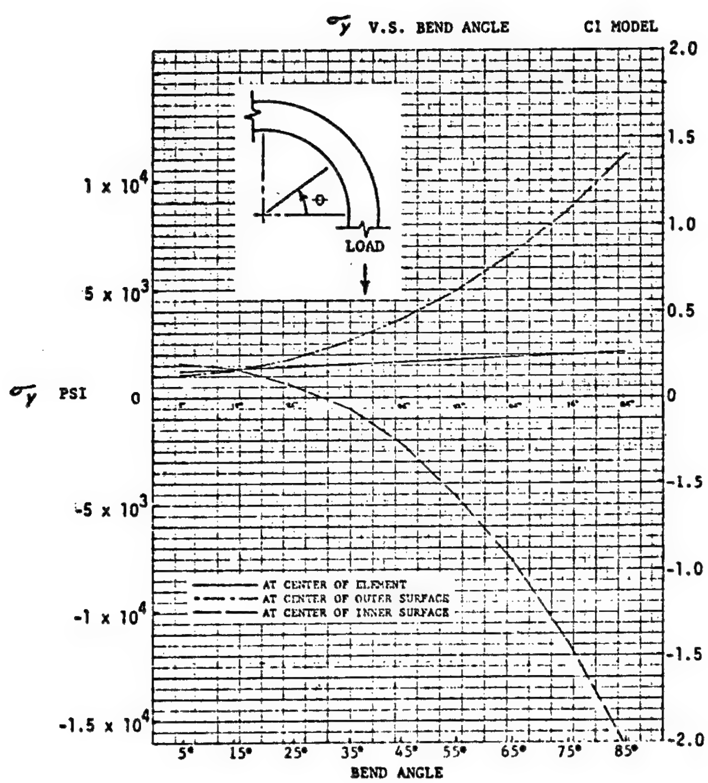
MODEL C 1



MODEL C 1







Hughes Helicopte

COMPOSITE
JOINTS &
FITTINGS

ANGLE BRACKET

Hughes Helicopte

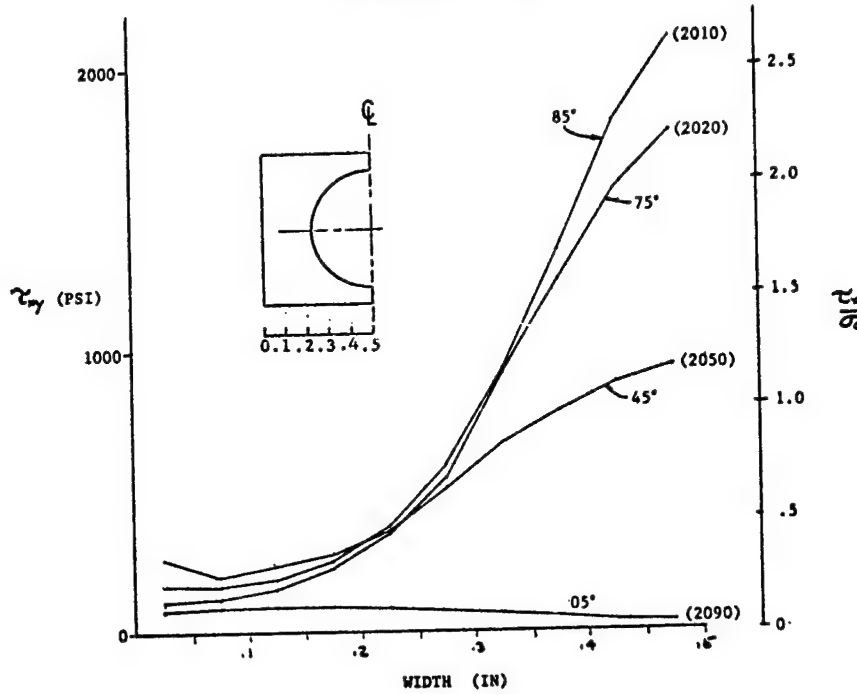
COMPOSITE
JOINTS &
FITTINGS

ANGLE BRACKET

COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

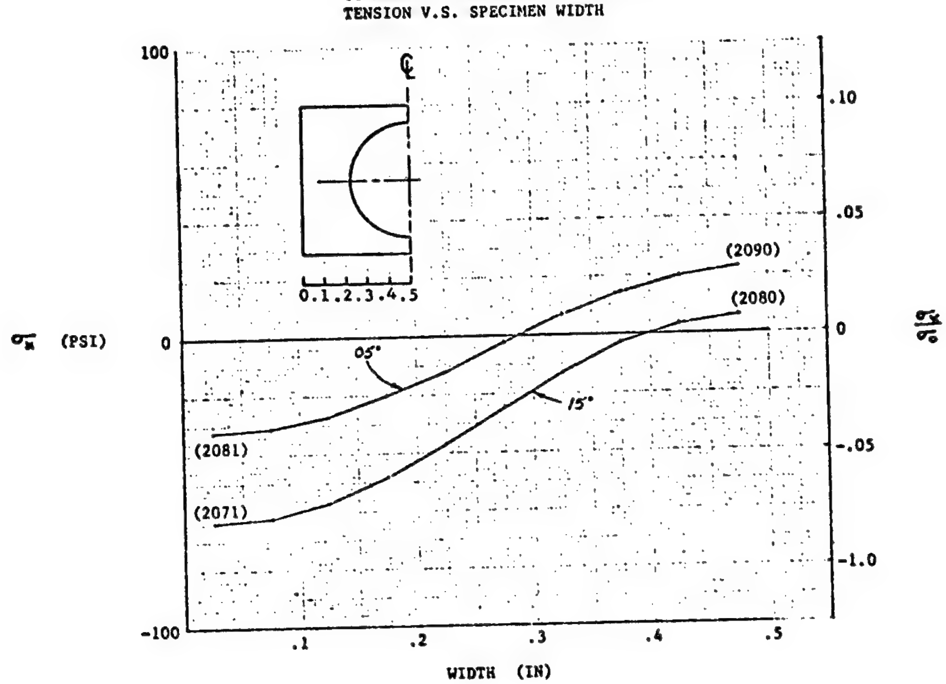
C1 MODEL: UNIFORM PULL
SHEAR STRESS V.S. WIDTH



COMPOSITE JOINTS AND FITTINGS

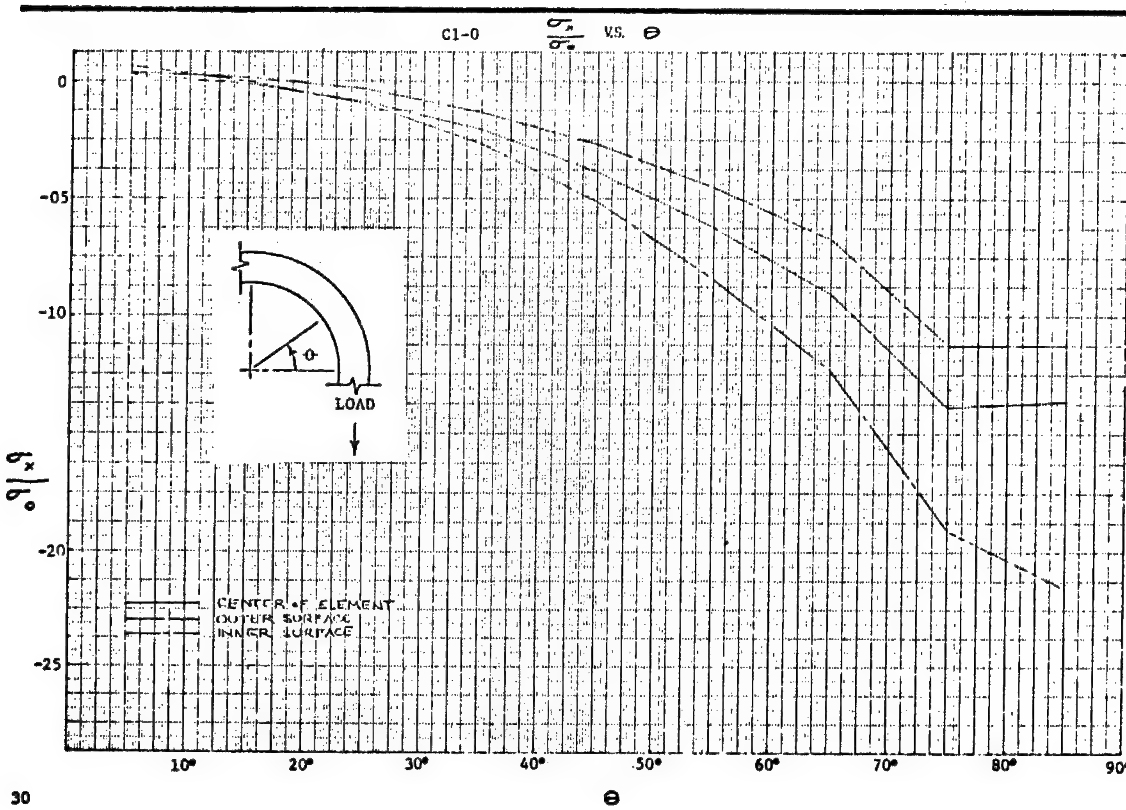
ANGLE BRACKET

C1 MODEL: UNIFORM PULL FLATWISE
TENSION V.S. SPECIMEN WIDTH



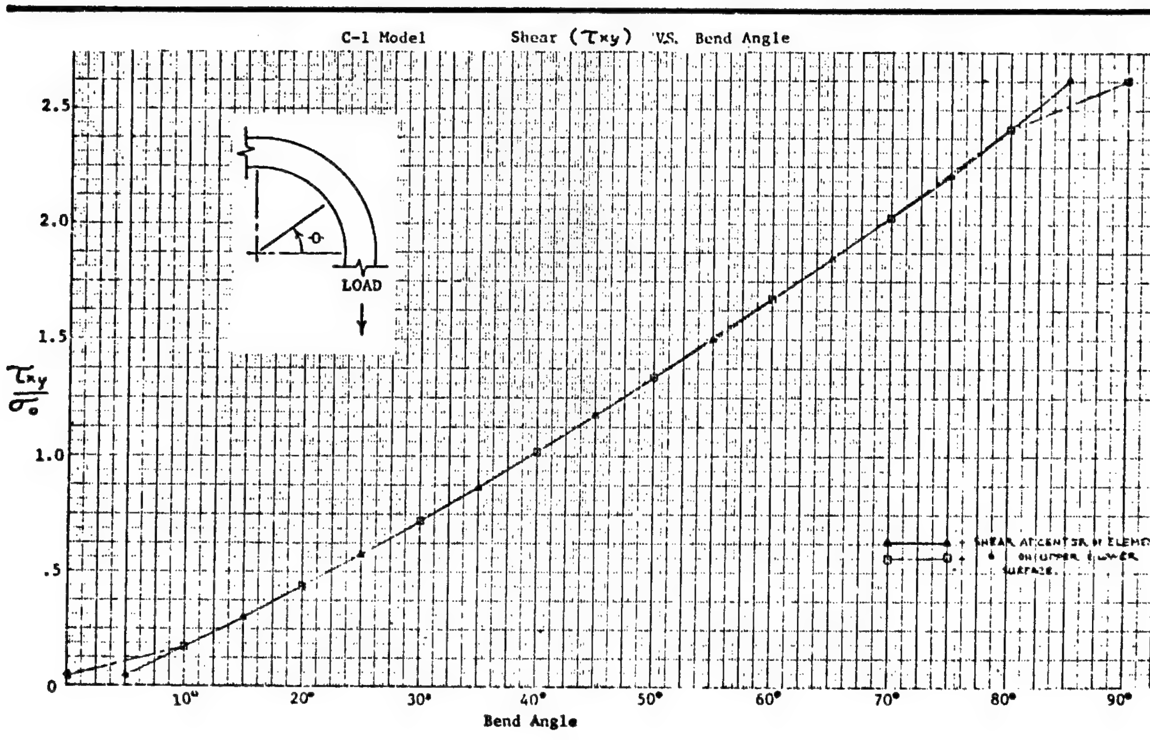
COMPOSITE JOINTS AND FITTINGS

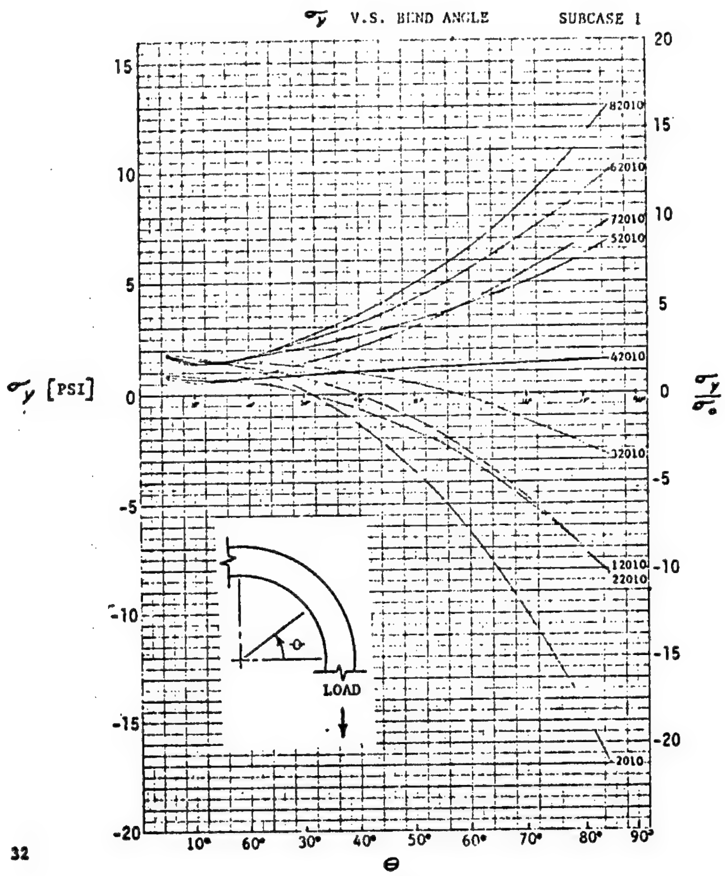
ANGLE BRACKET



COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET





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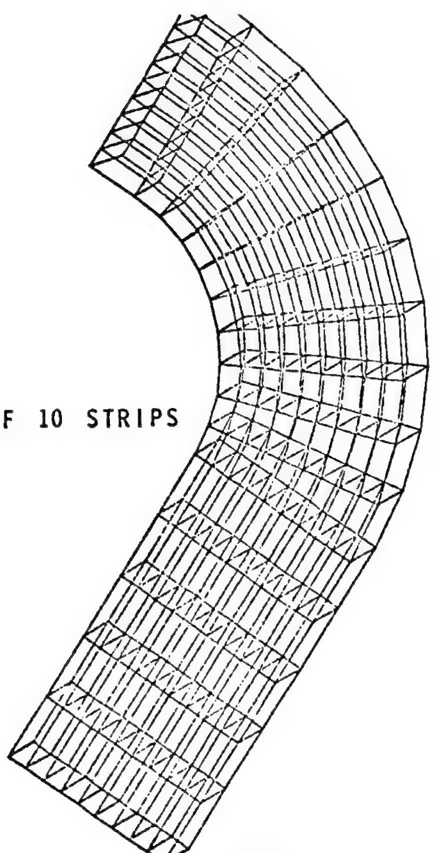


MODEL C2
FROM C1 OF 10 STRIPS

Hughes Helicopters

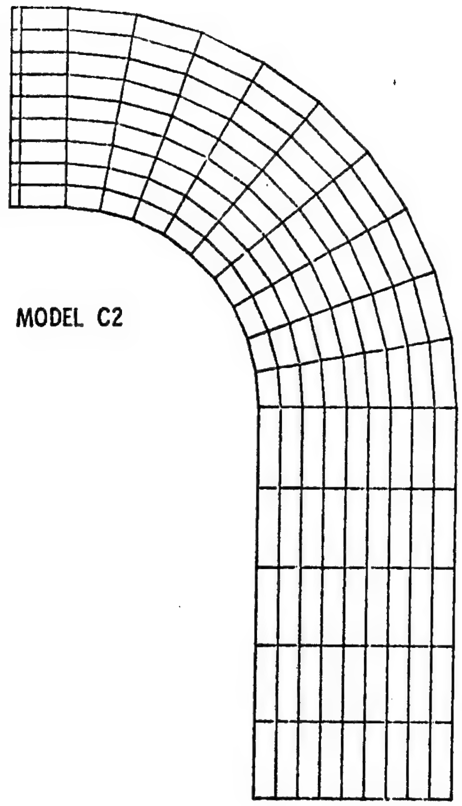
COMPOSITE
JOINTS &
FITTINGS

ANGLE BRACKET

Hughes Helicopters

COMPOSITE
JOINTS &
FITTINGS

ANGLE BRACKET

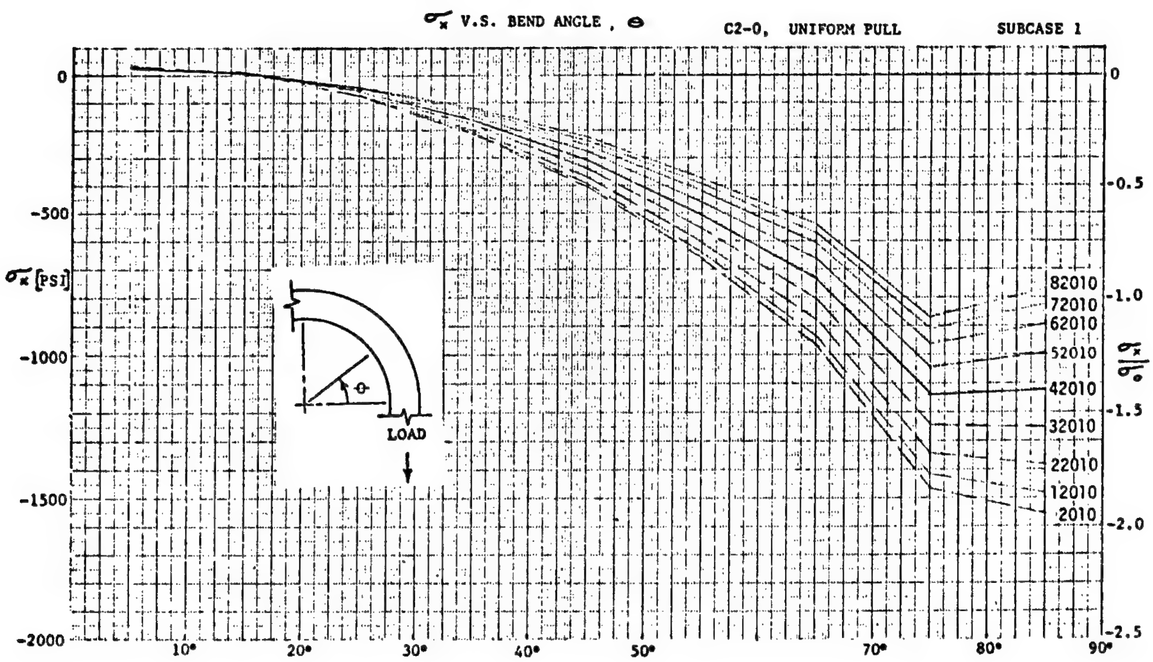


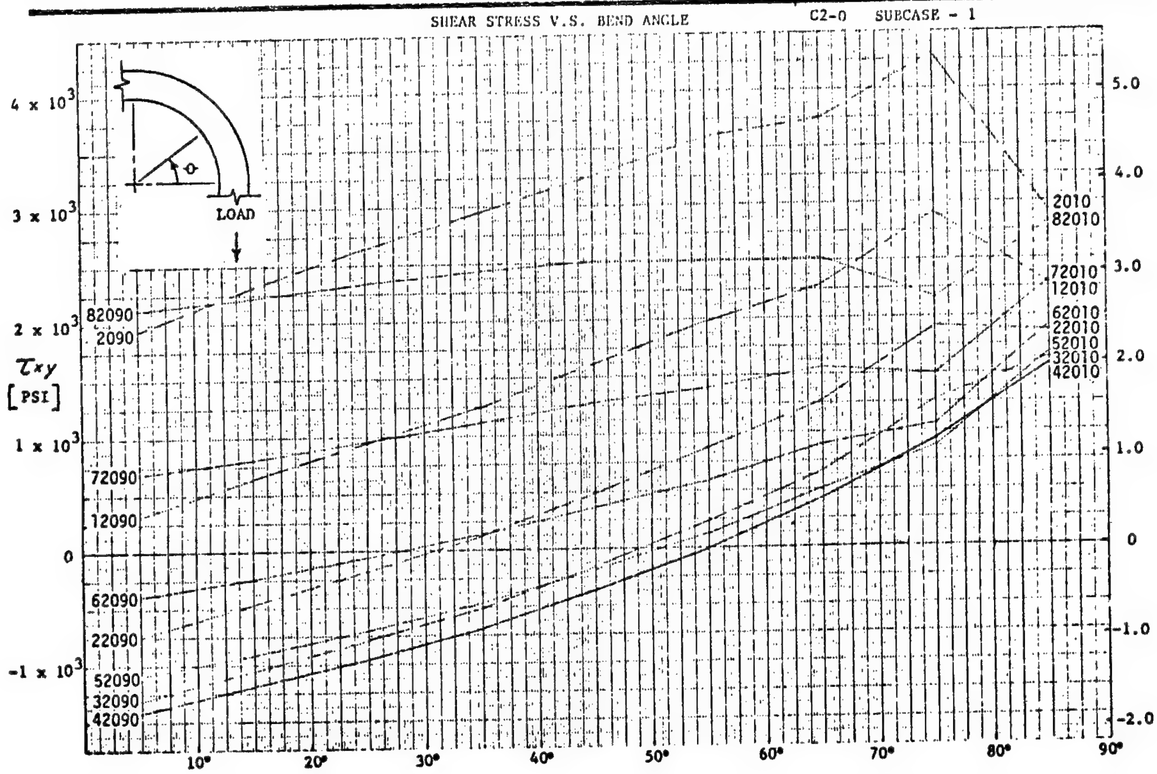
Hughes Helicopters

COMPOSITE
JOINTS &
FITTINGS

ANGLE BRACKET

COMPOSITE JOINTS AND FITTINGS
ANGLE BRACKET





COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

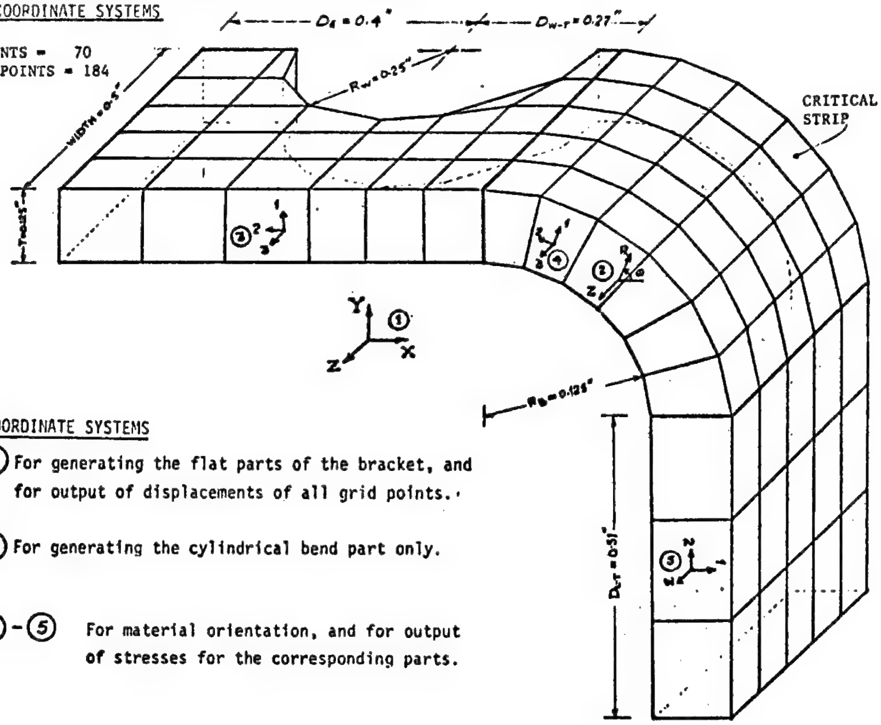
PARAMETRIC ANALYSIS

MODEL C - 1

RUN	BEND RADIUS	t	RAD WASH	MATERIAL	E.D.	D_{wt}	ΔT	D_{LTv}
1	.25	.125	.25	$[0_{17}/\pm 45_8]$	.4	.27	15°	.51
2	.50							
3	.125		.219	$[0_8/45_8/0_8]_3$		.249		.249
4			.25	$[0_{17}/\pm 45_8]$		.27		.51
5		.25						
6		.50						
7		.125		$[0_9/\pm 45_{16}]$				
8				$[0_{13}/\pm 45_{12}]$				
9				$[0]$				
10				$[\pm 45]$				

PREPROCESSOR GENERATED NASTRAN MODEL (C1-8), AND THE COORDINATE SYSTEMS

ELEMENTS = 70
GRID POINTS = 184

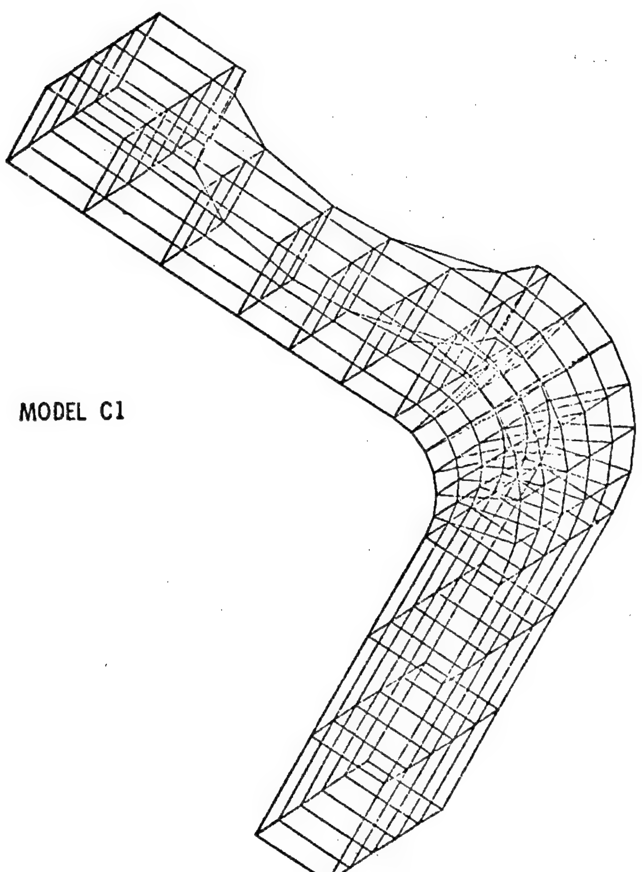


COORDINATE SYSTEMS

(1) For generating the flat parts of the bracket, and for output of displacements of all grid points.

(2) For generating the cylindrical bend part only.

(3)-(5) For material orientation, and for output of stresses for the corresponding parts.



MODEL C1

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COMPOSITE
JOINTS &
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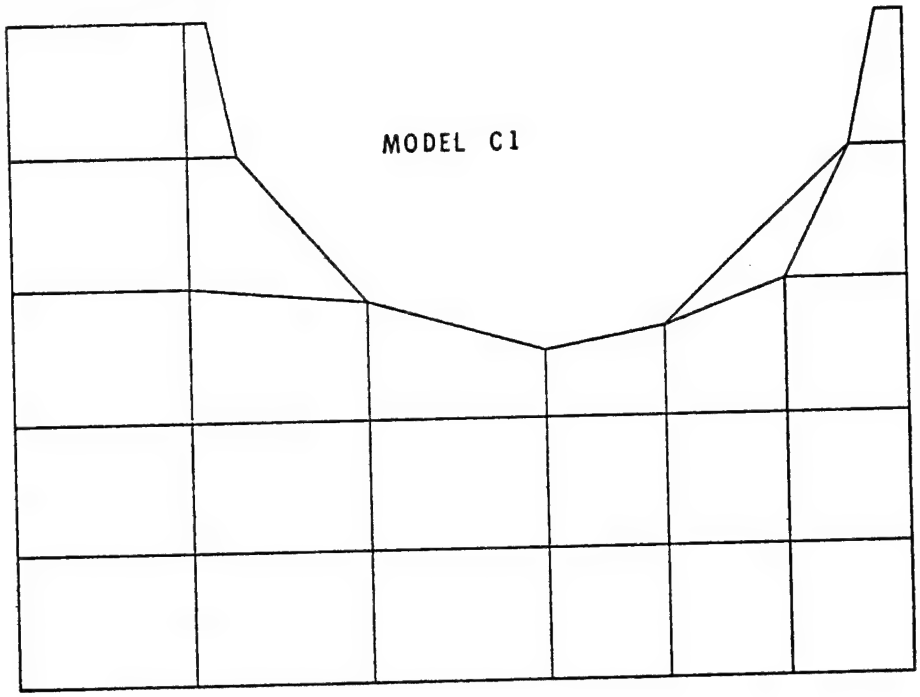
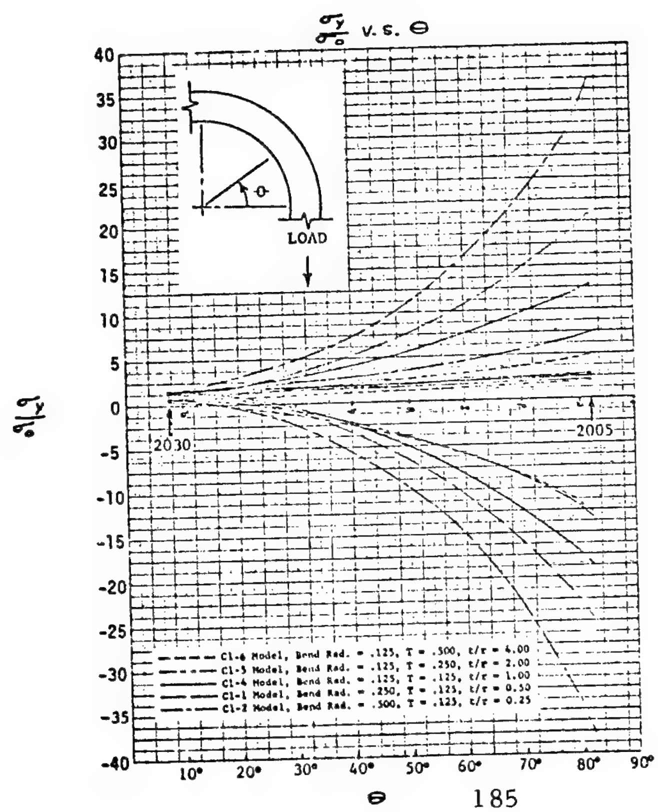
ANGLE BRACKET





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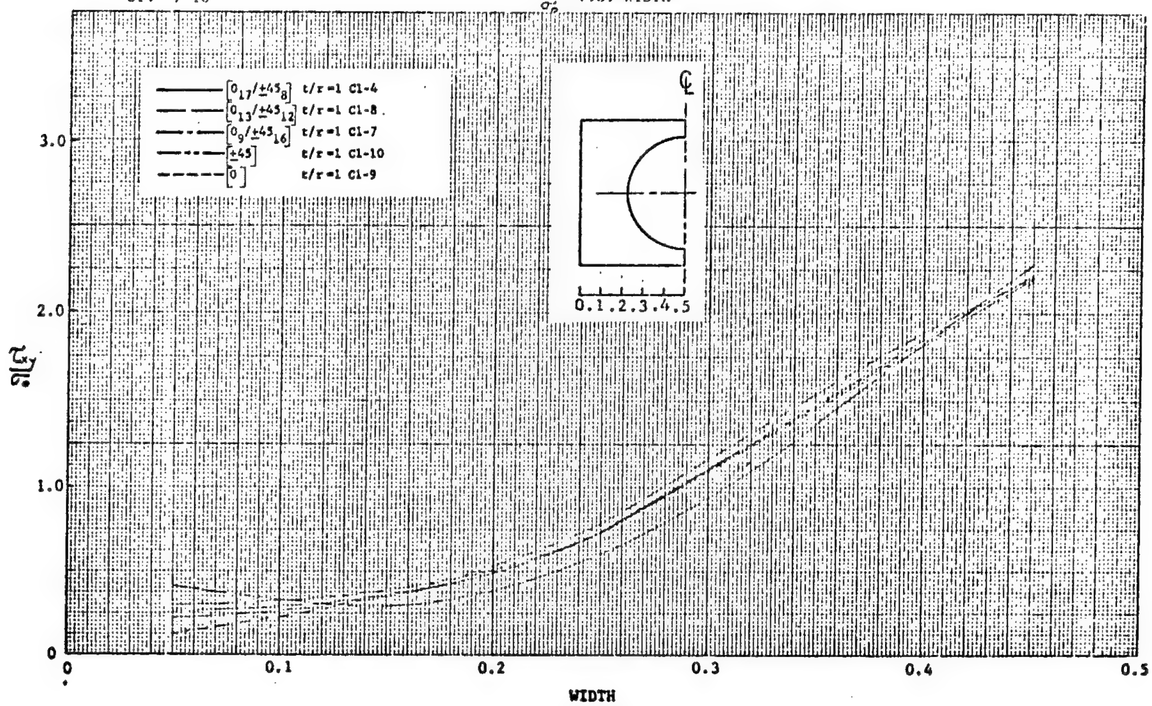
COMPOSITE
JOINTS &
FITTINGS

ANGLE BRACKET

C14 7-10

$\frac{\tau_{xy}}{\sigma_o}$ V.S. WIDTH

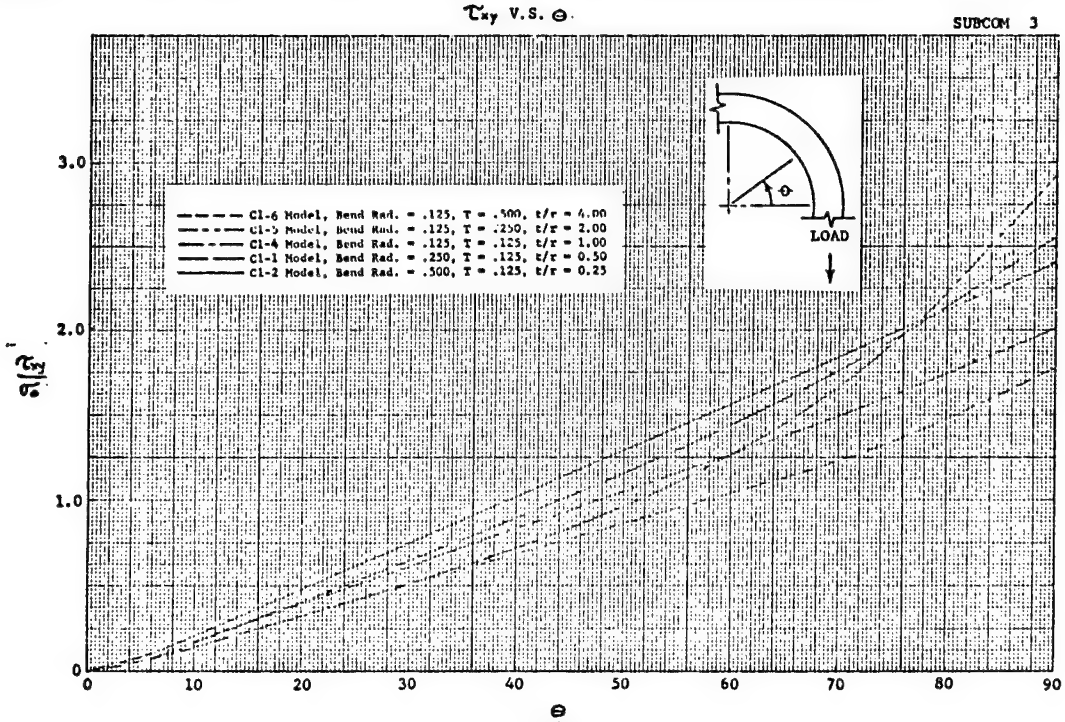


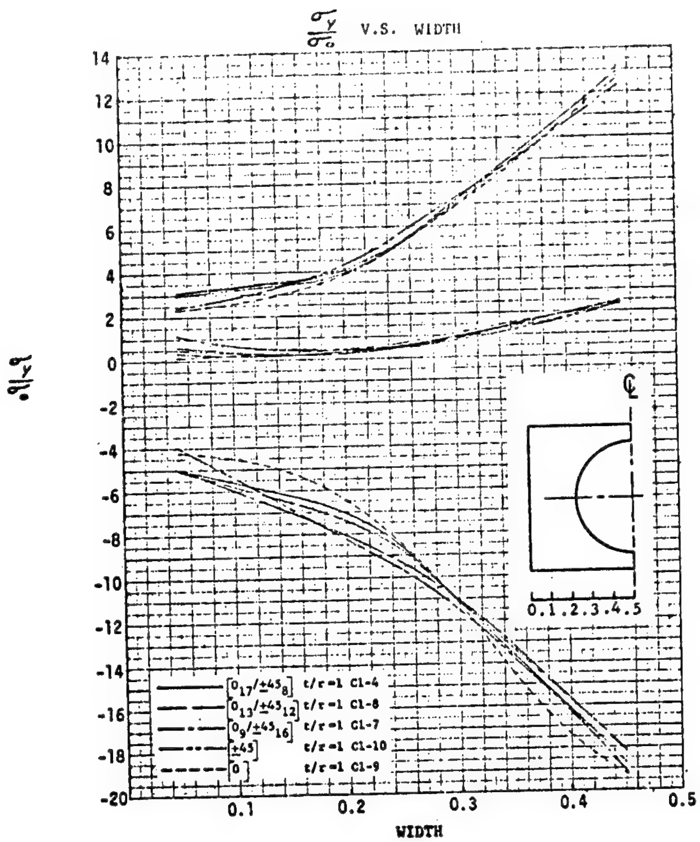
COMPOSITE JOINTS AND FITTINGS

ANGLE BRACKET

τ_{xy} V.S. θ

SUBCOM 3





Hughes Helicopters

COMPOSITE
JOINTS &
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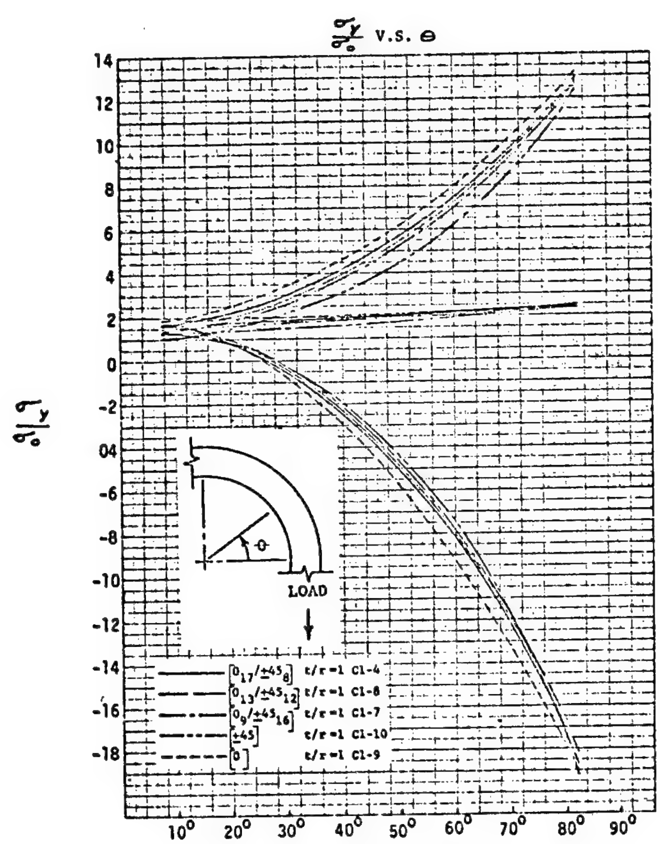

Hughes Helicopters

COMPOSITE
JOINTS &
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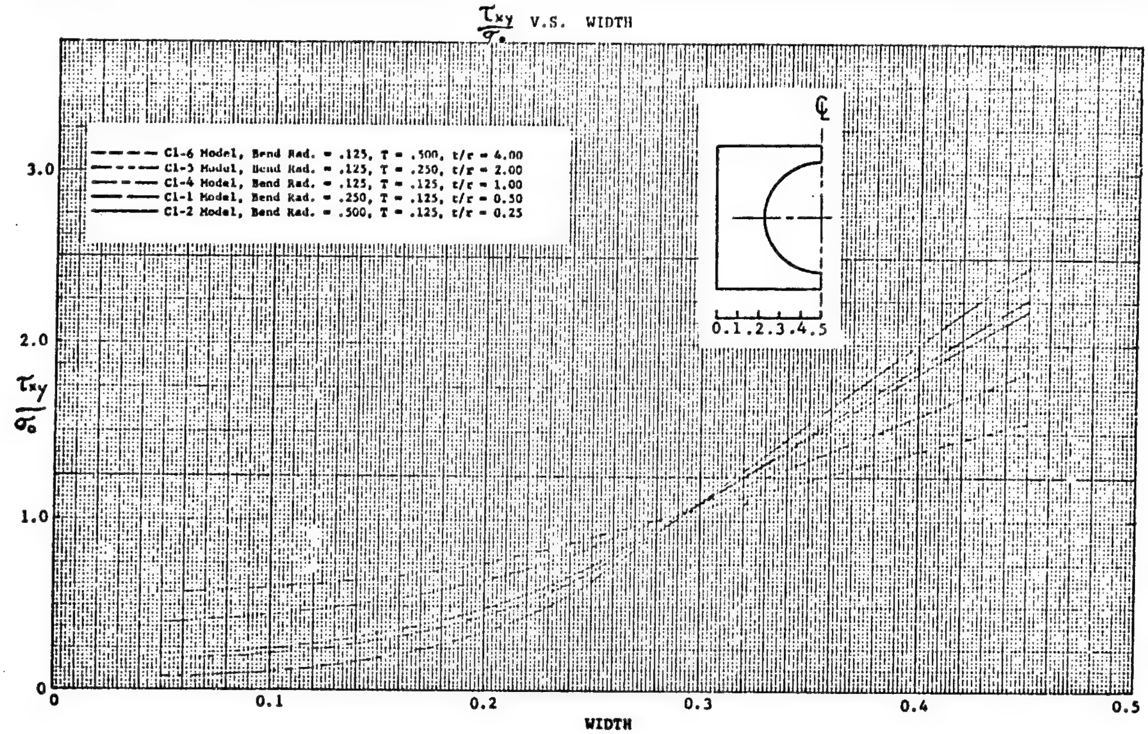
ANGLE BRACKET

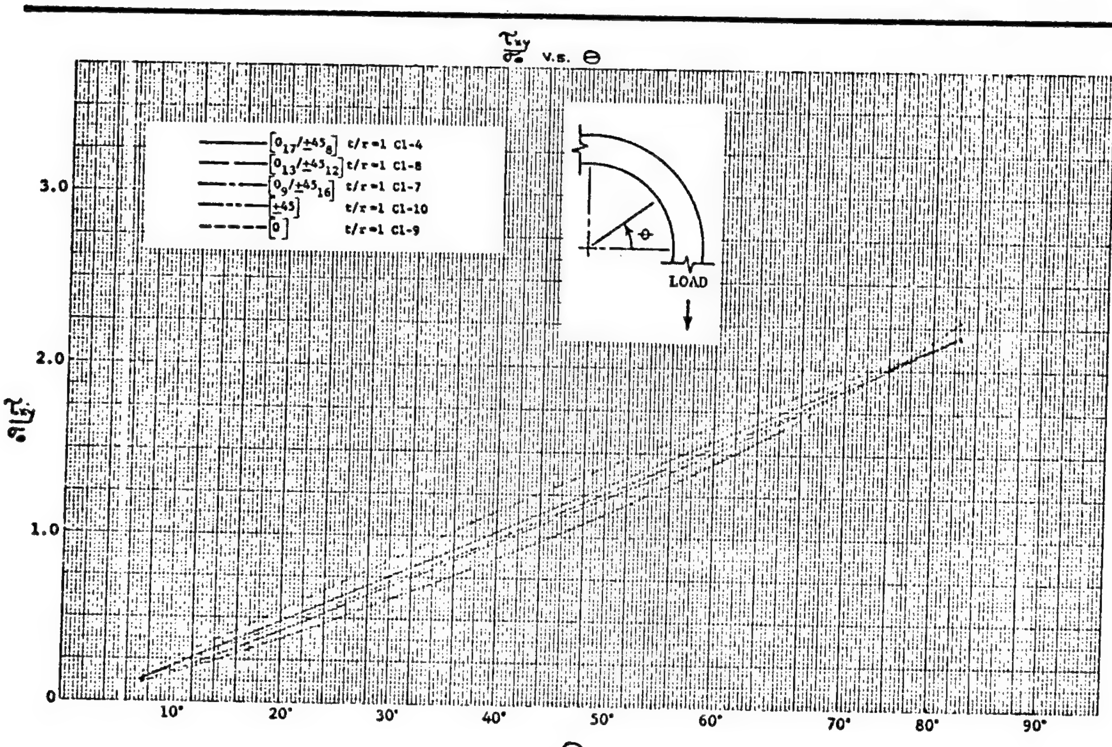
COMPOSITE JOINTS AND FITTINGS

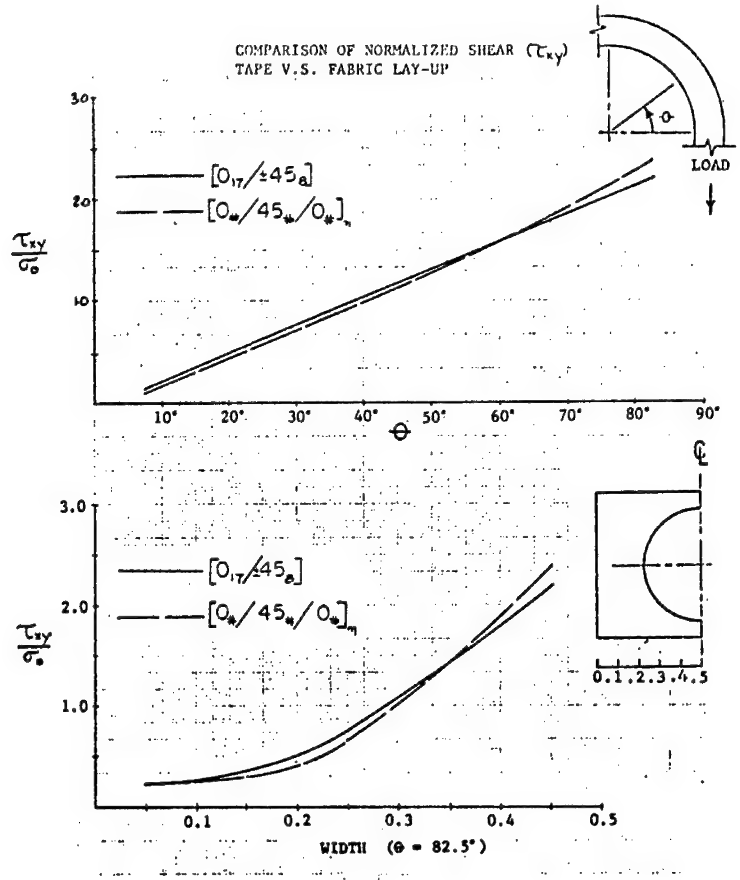
ANGLE BRACKET



COMPOSITE JOINTS & FITTINGS

ANGLE BRACKET





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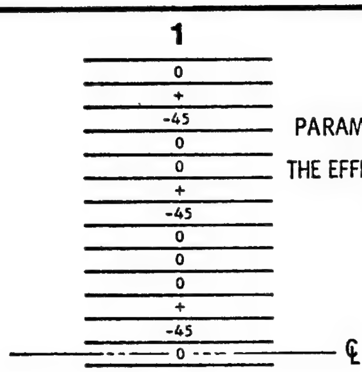
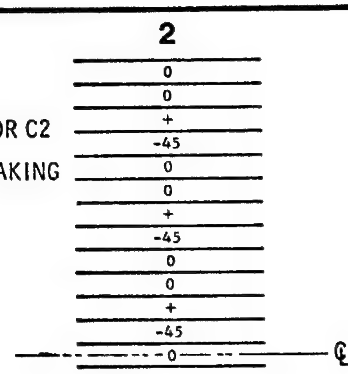
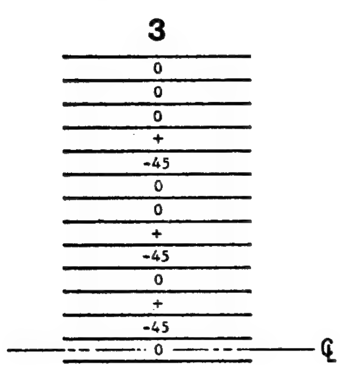
COMPOSITE JOINTS & FITTINGS

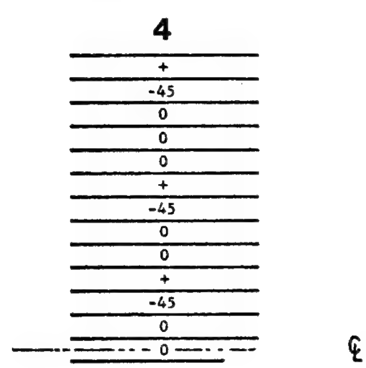
ANGLE BRACKET

PARAMETRIC STUDY FOR C2
THE EFFECT OF THE STAKING
SEQUENCE









"INVESTIGATION OF THE CRASH IMPACT CHARACTISTICS OF COMPOSITE HELICOPTER AIRFRAME STRUCTURES"

ARMY CONTRACT DAAJ02-77-C-0062

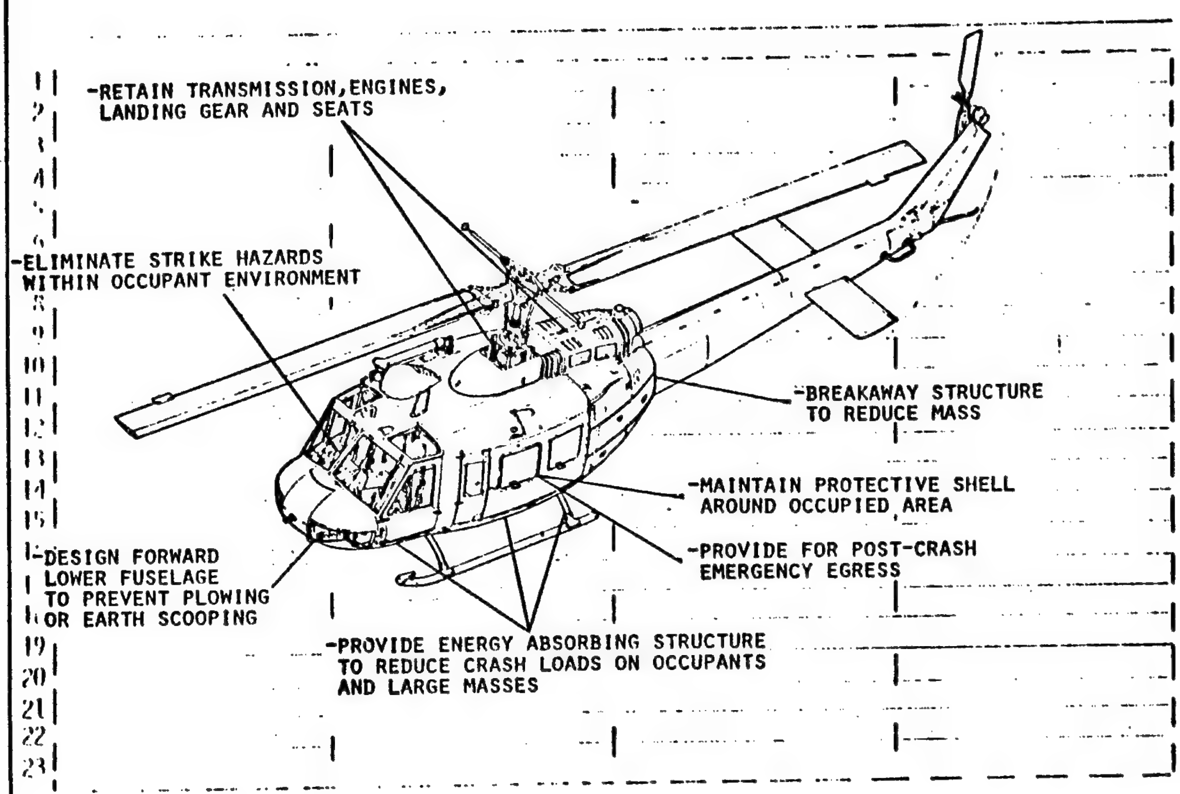
- LITERATURE SURVEY AND ASSESSMENT OF S.O.A.
- DESIGN CONCEPTS
- STRUCTURE CRASH SIMULATION ASSESSMENT
  - GRUMMAN "DYCAST"
- CONCLUSIONS AND RECOMMENDATIONS

BY : JIM CRONKHITE - BELL HELICOPTER TEXTRON

BOB WINTER - GRUMMAN AEROSPACE CORPORATION

VIEWGRAPH LAYOUT SHEET

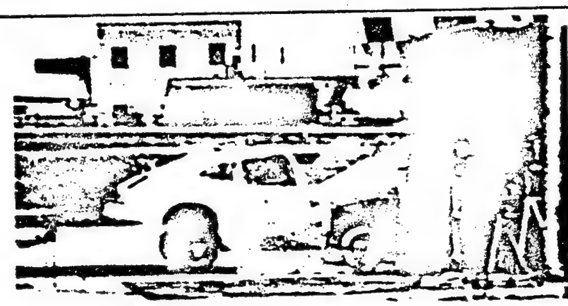
AIRFRAME STRUCTURE CRASHWORTHY DESIGN CONSIDERATIONS



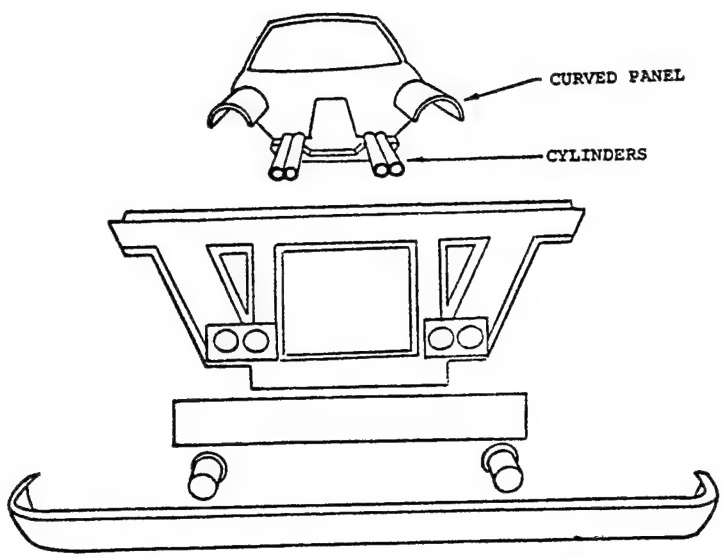
AVAILABLE CRASHWORTHINESS DESIGN CRITERIA

DESIGN CONSIDERATIONS	ARMY MIL-STD-1290 TR 71-22	NAVY AR-56	AIR FORCE MIL-A-8860 8865	FAA FAR 23,25 27 & 29
AIRFRAME PROTECTIVE SHELL	●	●		●
BREAKAWAY AIRFRAME STRUCTURE	●			
OCCUPANT STRIKE HAZARDS	●			
ENERGY ABSORPTION	●			
POST CRASH HAZARDS	●			
FAILURE MODES	●			
INERTIA FORCES TIEDOWN STRUCTURE	●	●	●	●

CRASH TEST OF COMPOSITE AUTOMOBILE FRONT END (BUDD CO.)



50 MPH BARRIER CRASH TEST



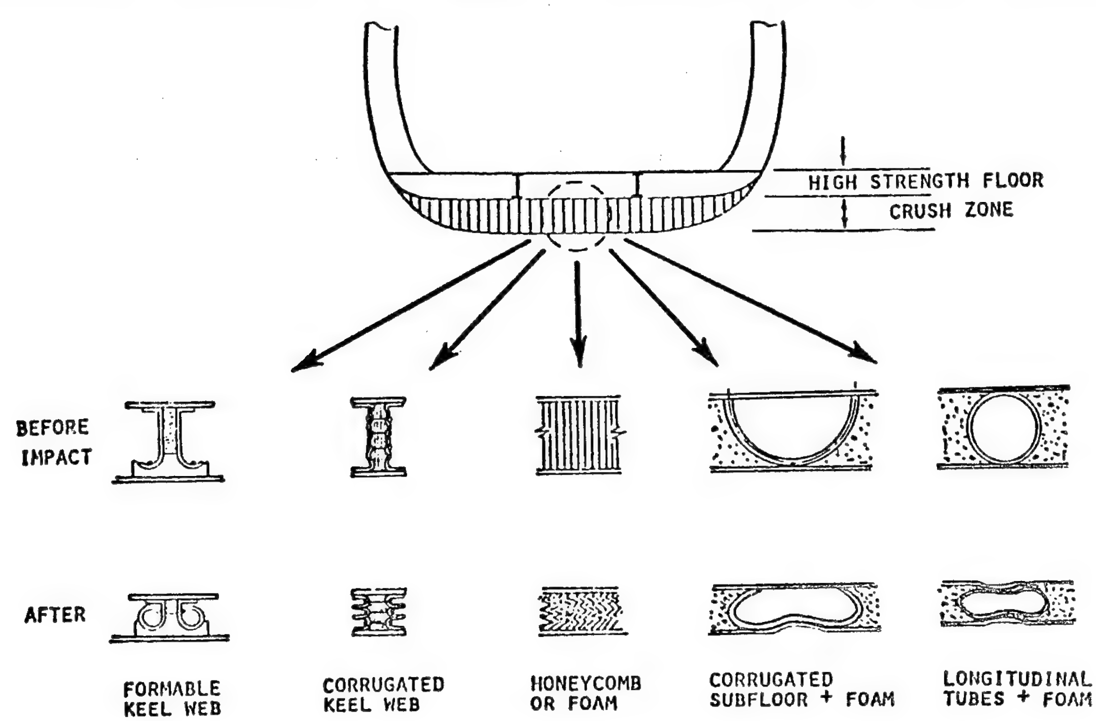
ENERGY ABSORBING FRONTAL STRUCTURE

RESEARCH IN-PROGRESS

- NASA - AIRFRAME CRASHWORTHY CONCEPTS
- BELL - COMPOSITE CYLINDER TESTS
- ARMY TESTING:
  - COMPOSITE STIFFENED CYLINDERS
  - FUSELAGE FLOOR SECTIONS

NASA/BELL

AIRFRAME CRASHWORTHY CONCEPTS - METAL



AIRFRAME CRASHWORTHY CONCEPTS - COMPOSITE

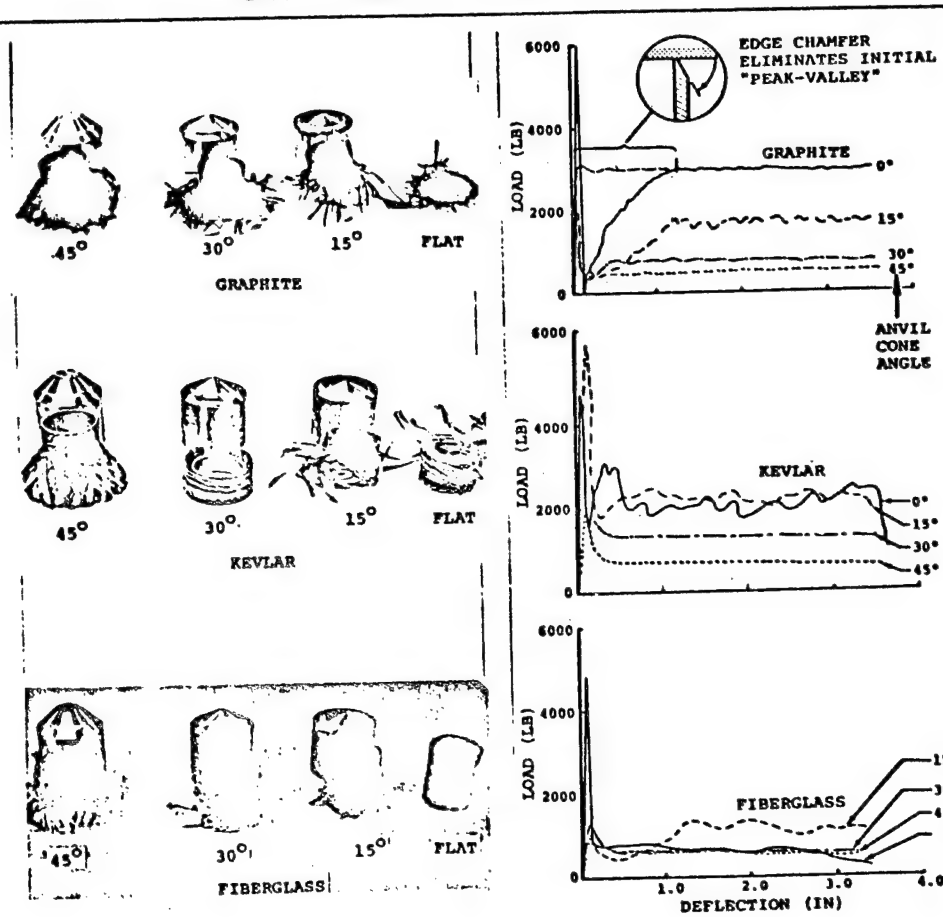
- HONEYCOMB OR FOAM WITH KEVLAR BELLY SKIN

- ENERGY ABSORBING COMPOSITE CRUSHABLE TUBES

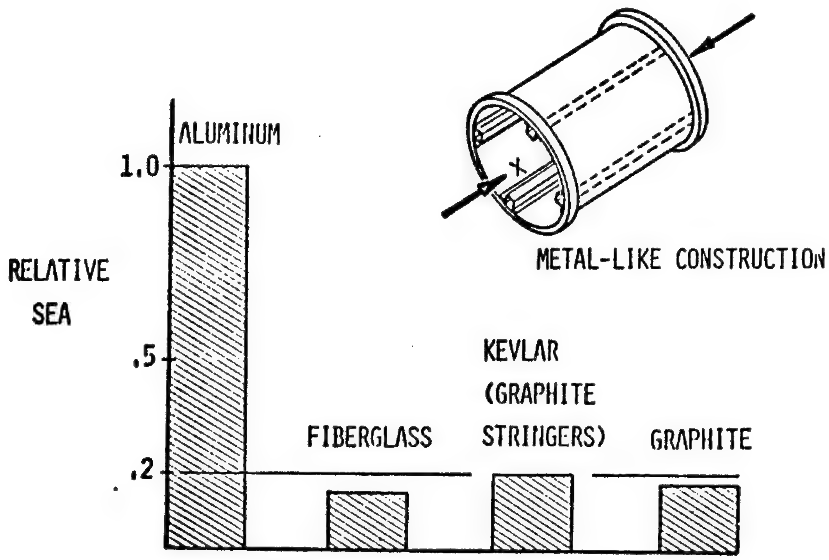
- FOAM AND COMPOSITE LONGI-TUDINAL TUBES

- KEVLAR/SEMI-RIGID FOAM/ FIBERGLASS BELLY PAN

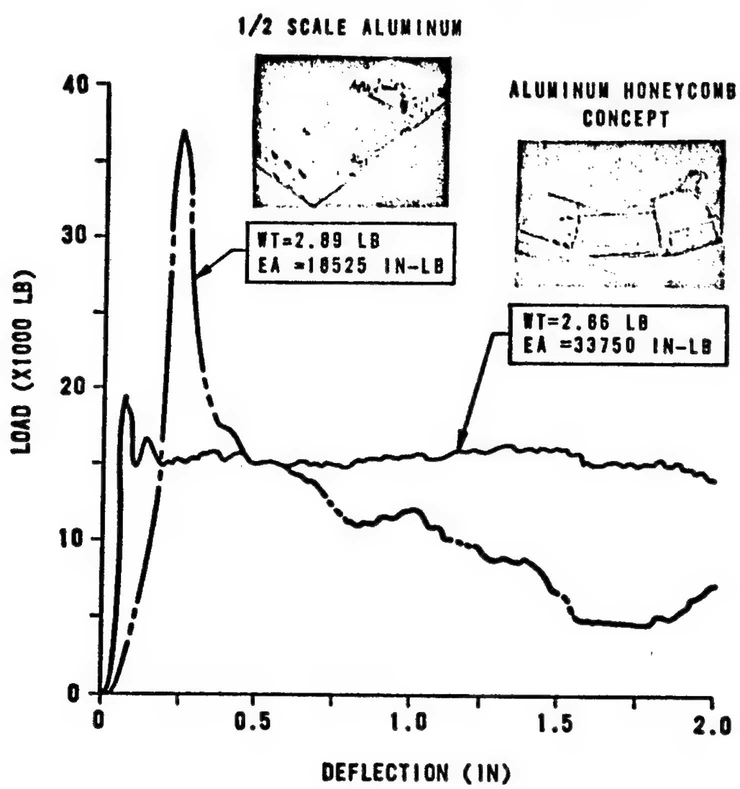
BELL - COMPOSITE CYLINDER TESTING



ARMY COMPOSITE STIFFENED CYLINDER TESTS -
ENERGY ABSORPTION COMPARISON



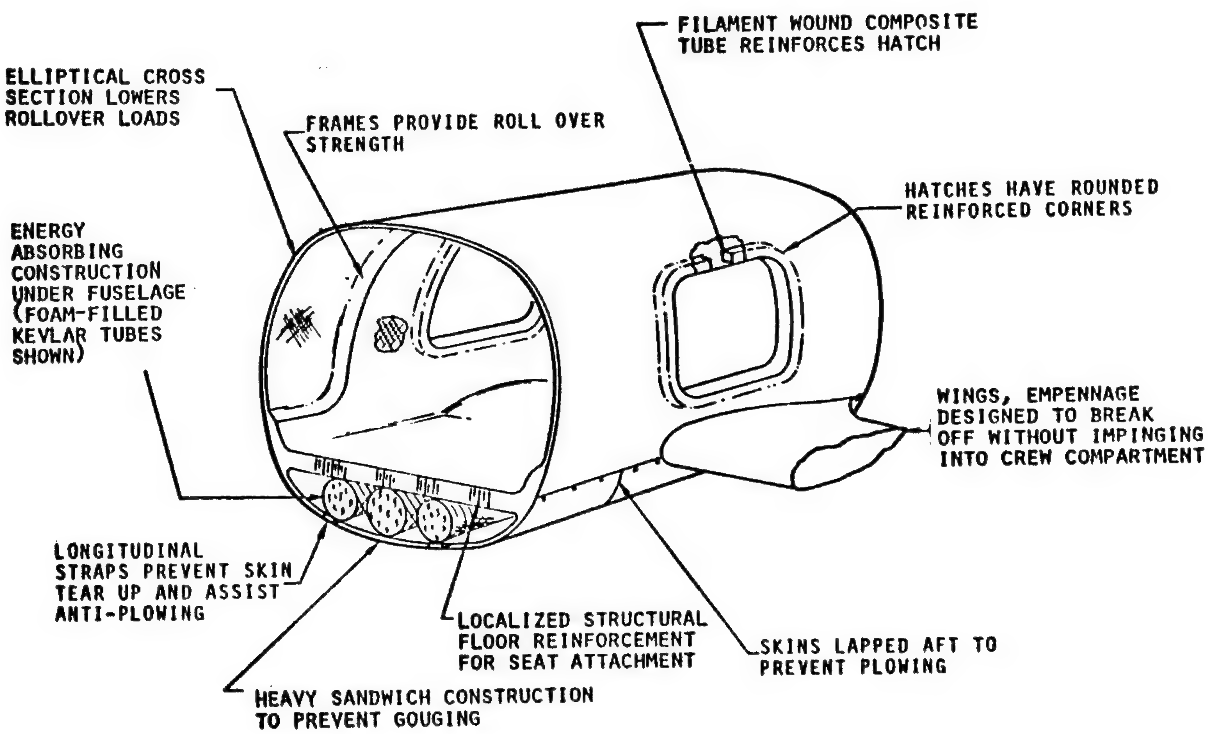
ARMY FUSELAGE SECTION TESTS



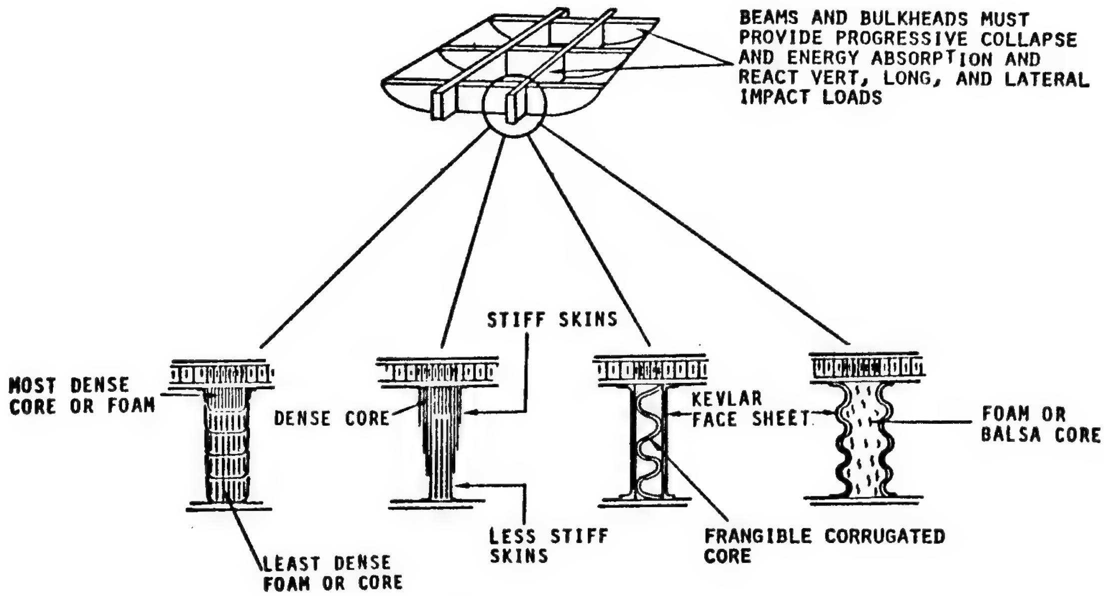
CONCLUSIONS

- VERY LITTLE DATA EXISTS ON CRASH IMPACT OF COMPOSITE STRUCTURES. SUMMARY OF DATA THAT WAS FOUND:
  - (AUTOMOTIVE WORK) SANDWICH CONSTRUCTION MORE CRASHWORTHY THAN SOLID LAMINATE (METAL-LIKE) CONSTRUCTION
  - (ARMY STIFFENED CYLINDER TESTS) COMPOSITES CONSTRUCTED LIKE METALS HAVE LOWER ENERGY ABSORPTION
  - (BELL AND BUDD CO. STUDIES) COMPOSITES PROGRESSIVELY CRUSHED HAVE GOOD ENERGY ABSORPTION CHARACTERISTICS
- CONSIDERABLE DATA EXISTS ON BASIC STRENGTH AND PROJECTILE/FOD IMPACT OF COMPOSITES, BUT NOT APPLICABLE TO CRASH IMPACT

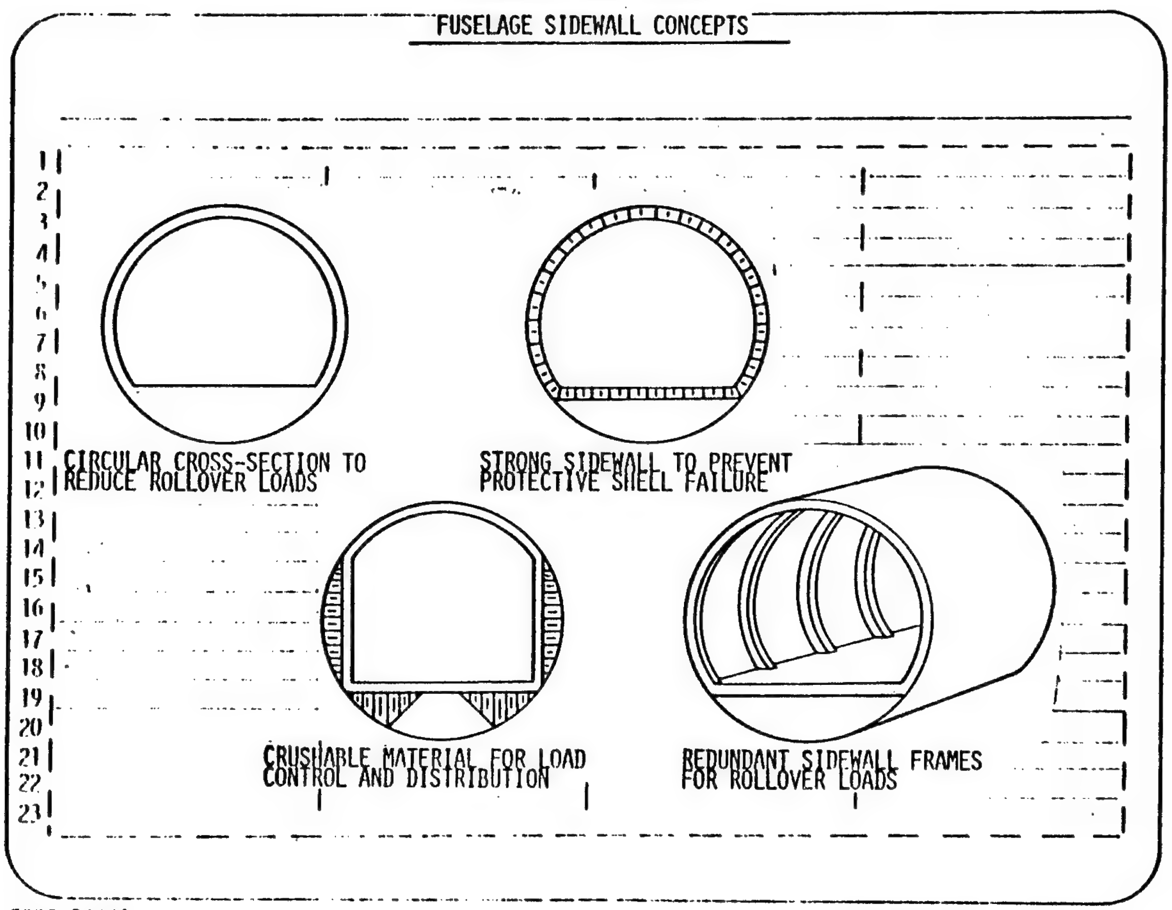
OVERALL FUSELAGE CRASHWORTHY CONCEPTS



ENERGY ABSORPTION CONCEPTS - BEAMS AND BULKHEADS



VIEWGRAPH LAYOUT SHEET



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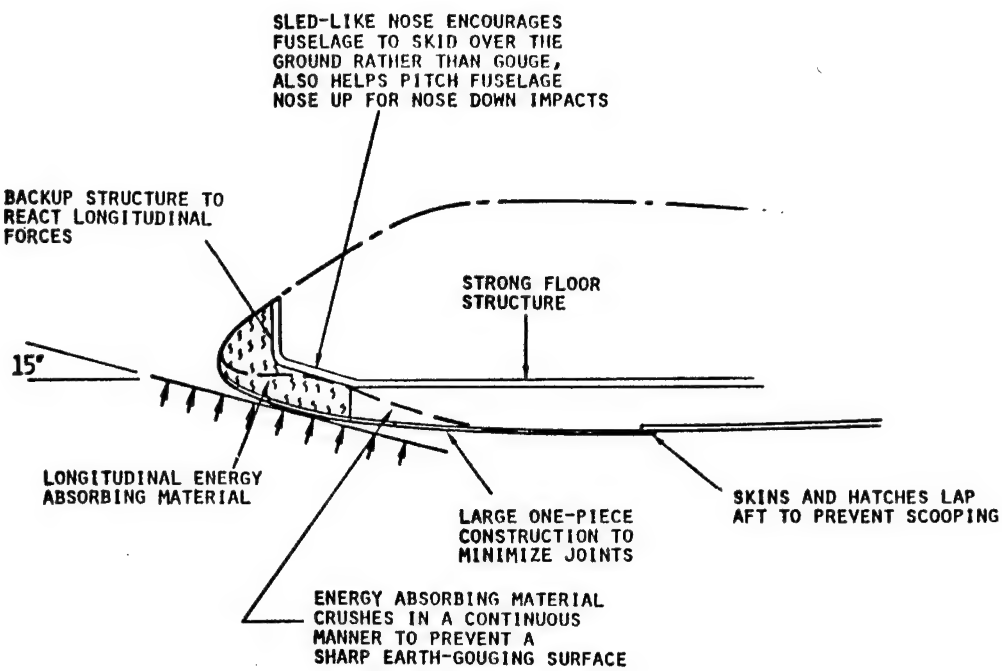
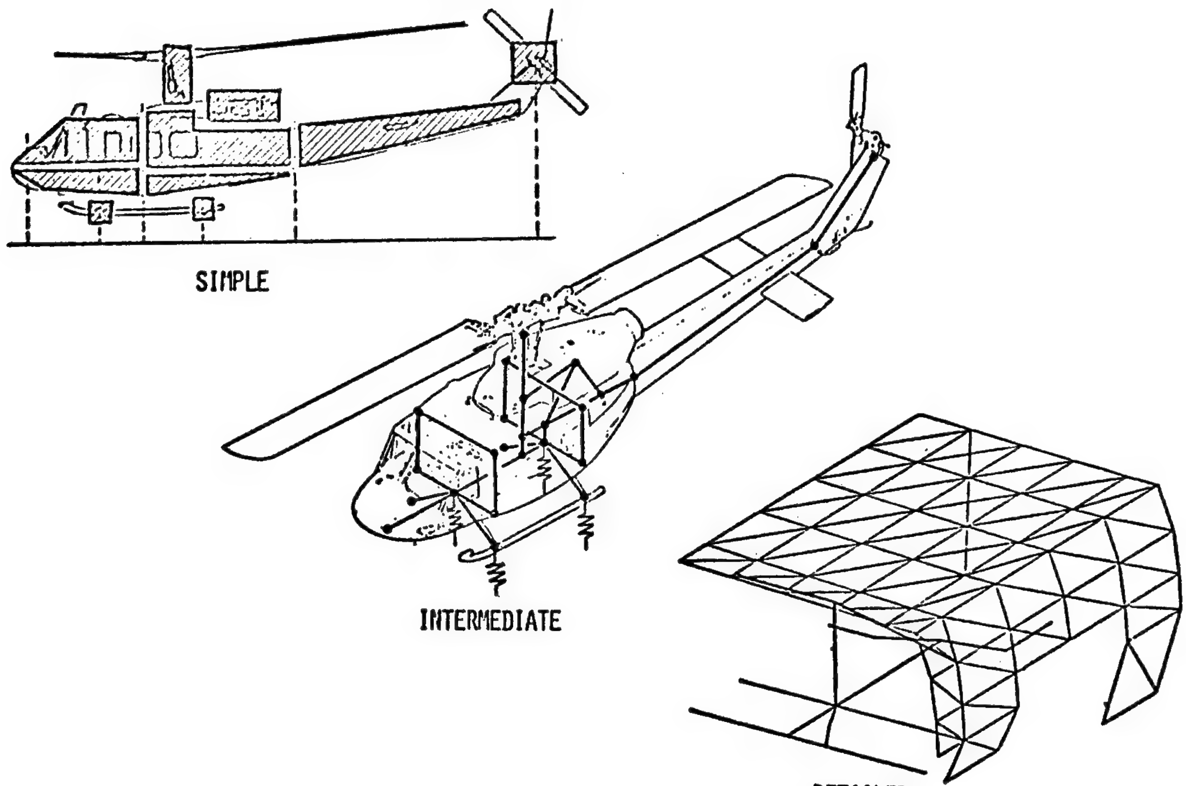
LONGITUDINAL IMPACT - ANTI-PLOWING CONCEPTS



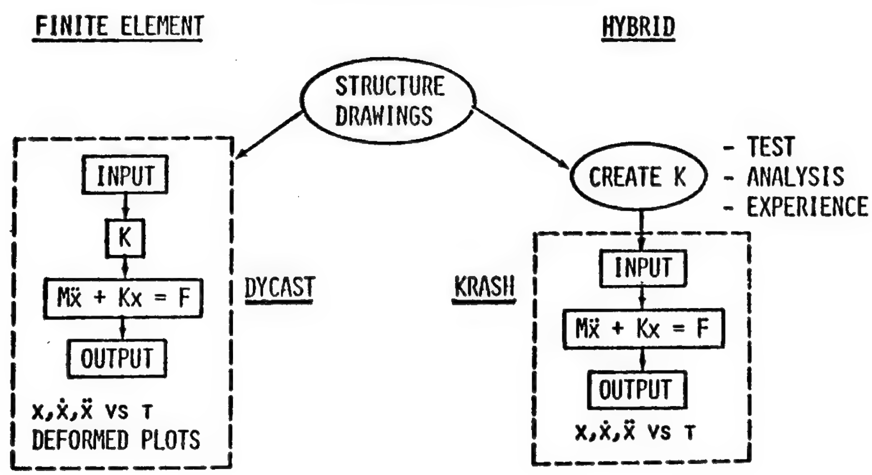
STRUCTURE CRASH SIMULATION ASSESSMENT

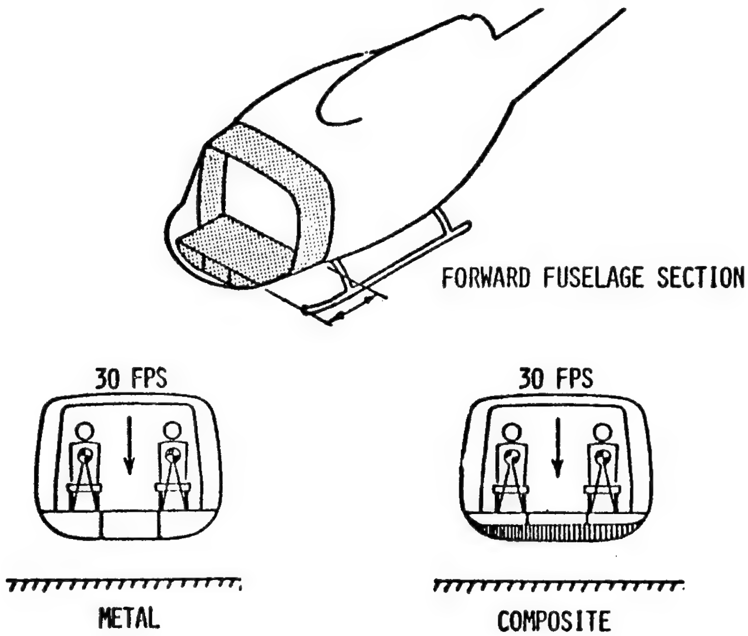
- GRUMMAN 'DYCAST' ANALYSIS - NASA/FAA FUNDED
  - METAL FUSELAGE SECTION
  - COMPOSITE FUSELAGE SECTION
- LOCKHEED 'KRASH' ANALYSIS - ARMY AND FAA FUNDED
  - TROOP TRANSPORT HELICOPTER 30 FPS VERTICAL IMPACT

MATH MODEL TYPES



HYBRID/FINITE ELEMENT ANALYSIS COMPARISON





PURPOSES

- EVALUATE RELATIVE CRASH RESPONSE UNDER 30 FPS VERTICAL IMPACT:
  - BASELINE CONVENTIONAL METALLIC FUSELAGE SECTION
  - ALL-COMPOSITE SECTION WITH ENERGY ABSORBERS

- EVALUATE DYCAST AS A DESIGN ANALYSIS TOOL

GRUMMAN

DYCAST MAJOR FEATURES

- o NONLINEAR SPRING, STRINGER, BEAM, & SKIN ELEMENTS
- o PLASTICITY
- o VERY LARGE DEFORMATIONS
- o VARIABLE PROBLEM SIZE
- o STOP, REVIEW & CONTINUE
- o DELETE FAILED MEMBERS
- o 4 DIFFERENT SOLUTION METHODS, 3 WITH INTERNAL VARIED TIME STEP
- o MODULAR FORMULATION

DYCAST

INPUTS

- GEOMETRY
- ELEMENT TYPES
- MATERIAL PROPS.
- RIGID MASSES
- IMPACT SURFACE
- INITIAL CONDITIONS
- CONTROL PARAMETERS

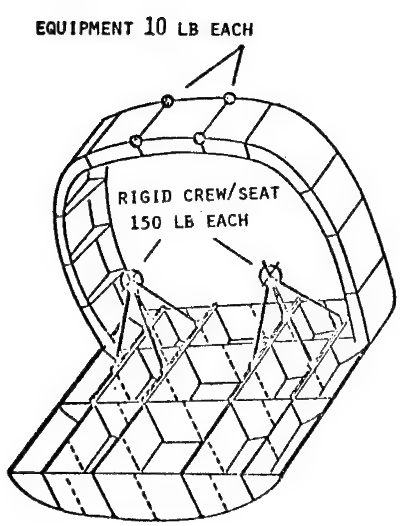
OUTPUTS

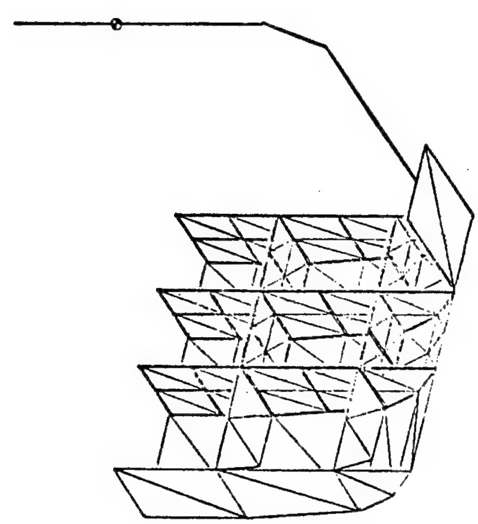
- PRINTED & PLOTTED HISTORY OF DISPL., VEL., ACCEL., STRAIN, STRESS, & LOADS AT CHOSEN PTS.
- TIME-SEQUENCE DRWGS OF DEFORMING STRUCT.

BASELINE METAL SECTION

ORIGINAL

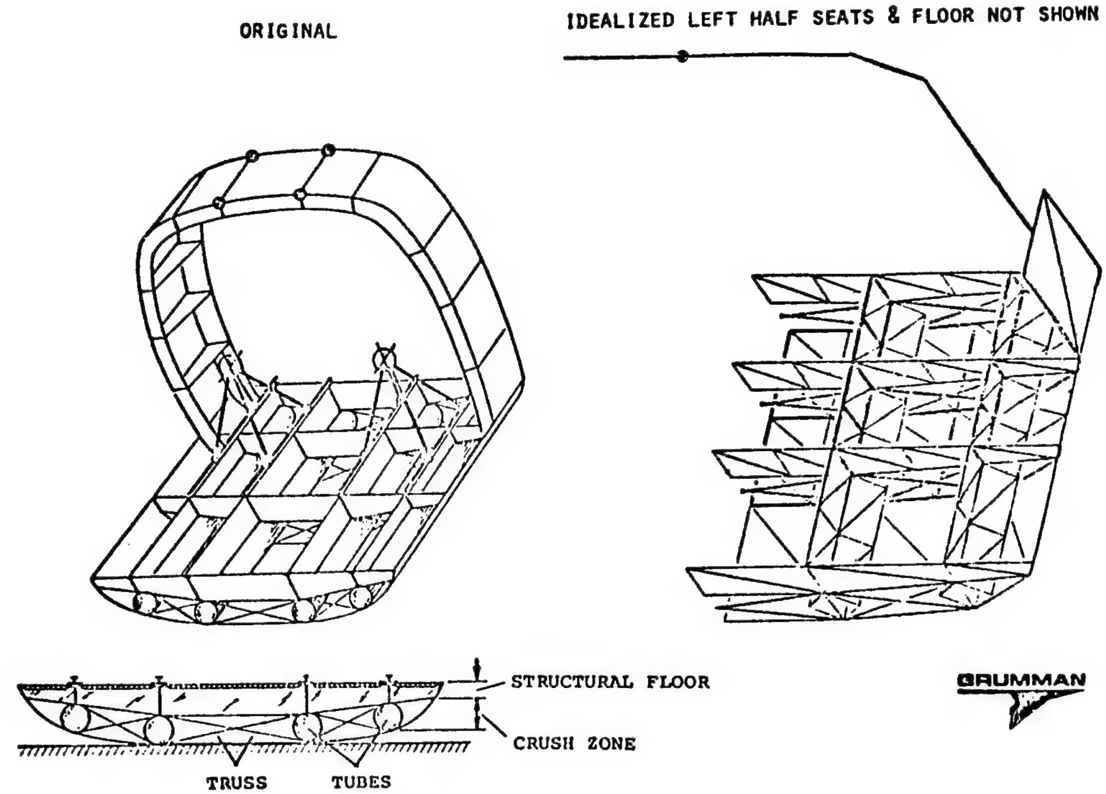
IDEALIZED LEFT HALF
SEATS & FLOOR NOT SHOWN



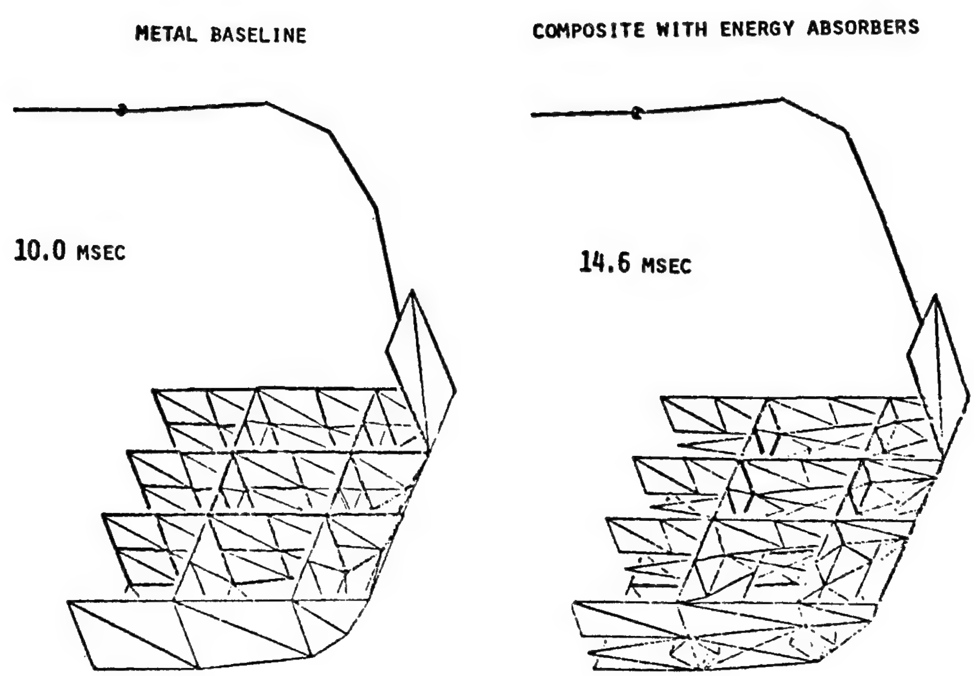


GRUMMAN

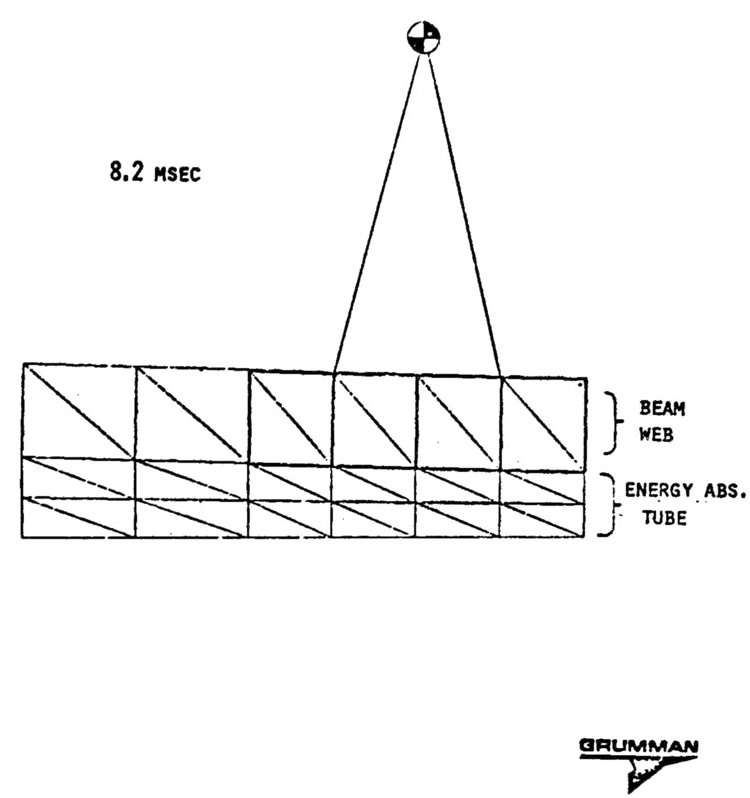
COMPOSITE SECTION WITH ENERGY ABSORBERS



DEFORMED SECTIONS



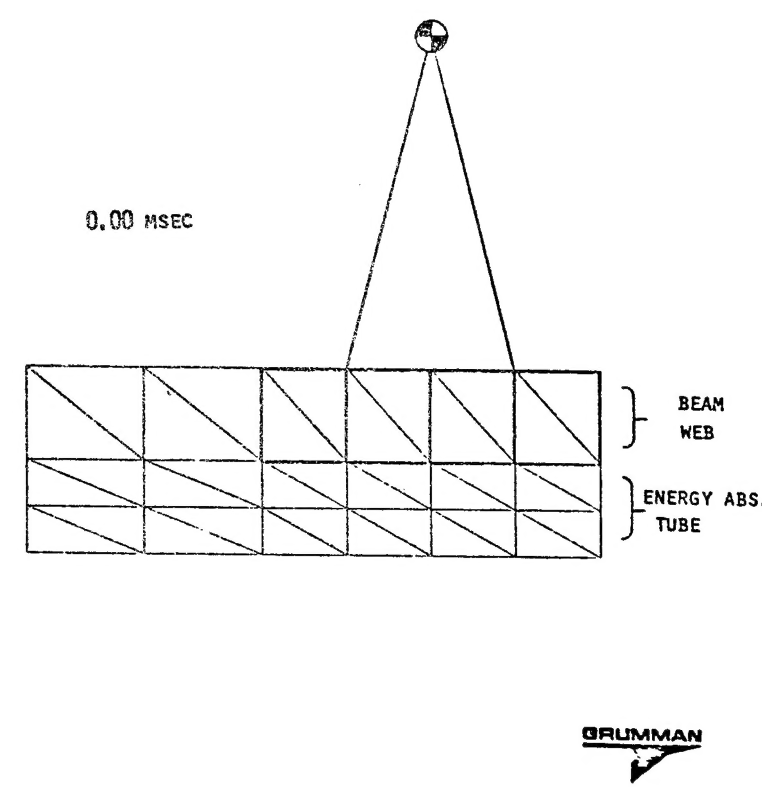
INBOARD BEAM & TUBE



HELICOPTER MODEL 2- 30FPS DROP

ALPHA	BETA	GAMMA	ORIENTATION	SCALE	INCREMENT	TIME
0.	0.	180.	Z Y T + + +	1/5	80	[illegible]

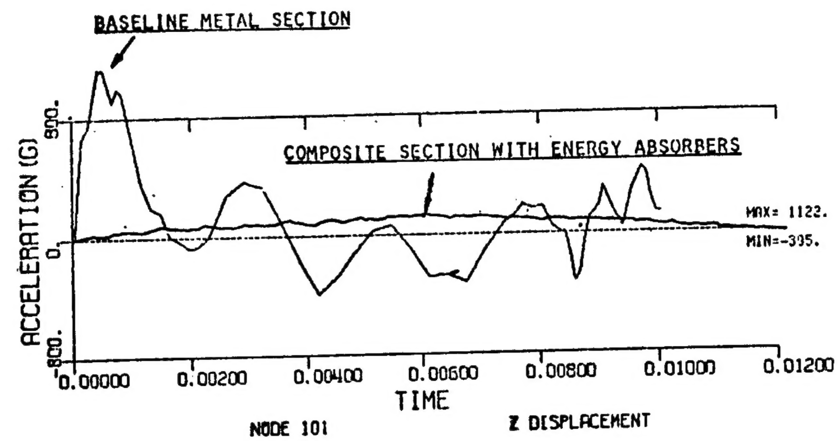
INBOARD BEAM & TUBE



HELICOPTER MODEL 2- 30FPS DROP

ALPHA	BETA	GAMMA	ORIENTATION	SCALE
0.	0.	180.	Z Y T + + +	1/5

RIGID CREW/SEAT VERTICAL ACCELERATIONS



SUMMARY OF DYCAST SIMULATIONS 30 FPS DROP

CONSTRUCTION	→	CONVENTIONAL ALUMINUM	ALL-COMPOSITE WITH ENERGY ABSORBERS
ASSESSMENT	→	SUBFLOOR VERY STIFF FOR THIS CONDITION.	REDUCED PEAK G's BY FACTOR OF 6. USED < 15% ABSORBER CAPACITY FOR THIS CONDITION.

ASSESSMENT OF DYCAST AS CRASHWORTHINESS DESIGN ANALYSIS TOOL

- SHOWED GROSS BEHAVIOR: OVERALL STRUCT. DEFORMATIONS, CRITICAL MASS MOTIONS
- SHOWED DETAILED RESPONSE: INDIVIDUAL COMPONENT BEHAVIOR OF METALS & COMPOSITES, INCLUDING STRESS, STRAIN DISTRIB., DEFORMATIONS AND LOADS
- INDICATED DETAILED MODIFICATIONS: OVERLOADED COMPONENTS & EQUIP. ATTACHMENTS, UNDERUSED ENERGY ABSORBERS
- MODERATE COST TO RUN: 1.9 CPU MINS/MSEC ON IBM 370/168 FOR 144 NODES, 422 ELEMENTS, 471 DOF (EXCLUDING GRAPHICS)
- CURRENT DEVELOPMENTS: REBOUND & SECOND IMPACT
AUTOMATIC FAILURE CRITERIA
- FUTURE DEVELOPMENTS NEEDED: SANDWICH PLATE ELEMENT
INJURY CRITERIA
ENERGY MANAGEMENT DATA
TEST VERIFICATION

GRUMMAN

MAJOR CONCLUSIONS

- STRUCTURE CRASH SIMULATION
  - AT PRESENT, BOTH HYBRID (KRASH) AND FINITE ELEMENT (DYCAST) CRASH ANALYSIS METHODS NEEDED - HYBRID FOR PRELIMINARY ANALYSIS OF ENTIRE AIRFRAME, FINITE ELEMENT FOR DETAILED STRUCTURE ANALYSIS AND INPUT TO HYBRID, BOTH NEED FURTHER WORK
  - PROBLEM GETTING INPUTS TO KRASH - NEED DATA BASE OF STRUCTURE RESPONSE
  - VALIDATION OF DYCAST NEEDED
- POTENTIAL DESIGN CONCEPTS PRESENTED FOR SEVERAL AREAS IMPORTANT TO A CRASHWORTHY DESIGN, THESE NEED FURTHER RESEARCH
- BASED ON THE RESULTS OF THIS STUDY, COMPOSITE AIRFRAME STRUCTURES SHOW PROMISE OF MEETING THE ARMY CRASHWORTHINESS REQUIREMENTS THROUGH INNOVATIVE DESIGN
- BECAUSE OF THE LACK OF DATA FOUND IN THE LITERATURE SURVEY, A COMPREHENSIVE LONG RANGE RESEARCH PROGRAM IS NEEDED TO DETERMINE THE CRASH IMPACT BEHAVIOR OF COMPOSITE STRUCTURES

PROPOSED LONG RANGE R&D PLAN

1. SET GOALS
   - DESIGN C/W COMPOSITE HELICOPTER AIRFRAME
   - NEED: DESIGN DATA, ANALYTICAL TOOLS, REQUIREMENTS
2. STANDARDIZE TESTING METHODS
3. DEVELOP FIRM AND RELIABLE DATA BASE - COMPARE COMPOSITES TO METALS
4. DEVELOP ANALYTICAL TOOLS
5. INTEGRATE WITH RELATED DEVELOPMENTS: ENVIRONMENT, SEATS, ROTOR, LANDING GEAR
6. UPDATE ARMY "CRASH SURVIVAL DESIGN GUIDE" TO REFLECT RESULTS
7. INDUSTRY/GOVERNMENT ADVISORY GROUP TO ENCOURAGE PARTICIPATION AND GUIDE PROGRAM

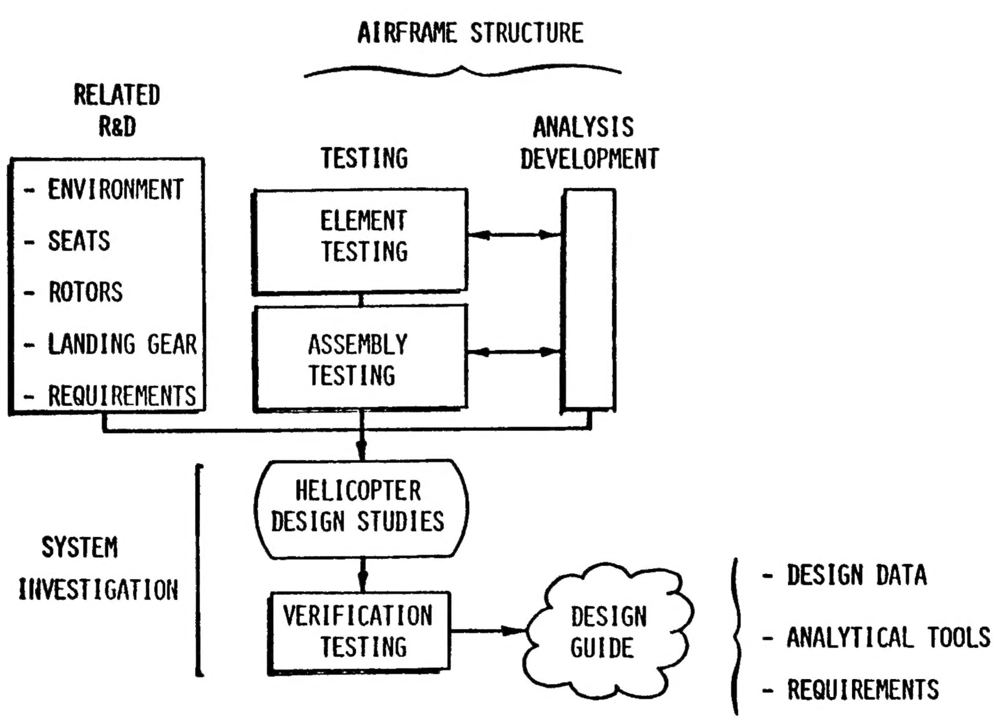
ELEMENT INVESTIGATION

MFG METHOD	CATEGORIES	SPECIMENS	LOADING
LAB (IDEAL)	1. ENERGY ABSORBING CONCEPTS	- LAMINATES	- STATIC
		- PANELS	- DYNAMIC
FACTORY	2. CONVENTIONAL STRUCTURE	- SHAPES	- COMBINED
		- JOINTS, SECTIONS	
	3. CONCENTRATED LOADS, ATTACHMENTS, CUTOUTS	- FITTINGS, HARDPOINTS	

ASSEMBLY INVESTIGATION

MFG METHOD	CATEGORIES	SPECIMENS	LOADING
LAB	1. C/W DESIGN CONCEPTS	TYPICAL AIRCRAFT SECTIONS:	- STATIC
FACTORY	2. CONVENTIONAL STRUCTURES	- FLOOR	- DYNAMIC
	3. INNOVATIVE DESIGNS AND MFG METHODS	- FRAME	- COMBINED
		- STIFFENED CYLINDER (LOAD RADIAL & AXIAL)	
		- MONOCOQUE	

PROPOSED RESEARCH PROGRAM



☆U.S.Government Printing Office: 1978 — 657-002/157